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The Influence of Stimulus Duration on Reaction Time

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I. INTRODUCTION

In 1820 Bessel established beyond doubt the fact of the "personal equation", the existence of which had been indicated twenty-five years earlier by the historic disagreement between Maskelyne and his assistant over the timing of the transit of a star.[47] Later, the chronograph was introduced and took the place of the eye and ear method used by Maskelyne and Bessel. The use of the chronograph reduced the "personal equation" factor, but did not eliminate it. The "personal equation" involves, *inter alia,* the time elapsing between an expected stimulation and a muscular reaction to that stimulation. Since that time the reaction movement and its consciousness have been examined from almost every possible angle. The conditions of experiment have been carefully arranged and varied; in particular, the quality and intensity of the stimulus have been carefully controlled and the effect on reaction time of changes in these factors noted, and the influence of the general physiological condition of the reactor has been studied.

It would seem that of all fields open to psychological study that of reaction time offered least promise of yielding new fruits to labor. The complexity of the conditions governing the reaction movement and the stimulus would, of course, allow of endless permutations and combinations of these two factors. But unless the rearranging of conditions were done with some particular problem in view it would be less than worth while to do so.

The present investigation did not start with the idea of merely making a new combination of the conditions of reacting, but starting with a problem somewhat different from that which was finally worked out, was driven to the latter, because it is an essential step in the solution of the former problem and it had received very little attention.

The original intention was to investigate the characteristic difference between auditory and visual reaction times, and to

ascertain the conditions under which this difference obtained. It was suggested that as the physiological effect of the stimulus on the retina was probably of longer duration than the effect of sound waves on the hearing mechanism, some light might be thrown on the characteristic difference in the reaction times to stimuli of different modes if the effects of varying the duration of the stimulus were known. For some reason or other little or no attention has been paid in reaction time experiments to the part played by the duration of the stimulus. Most of the authors neglect this factor altogether; one or two assume[59] that the effect of increasing the duration of the stimulus is the same as the effect of increasing the intensity, and shortens the reaction time. That this is the effect of variations in intensity of the stimulus has probably been established.

The only one who has made any attempt to vary experimentally the duration of the stimulus is Sven Froeberg.[32]

Froeberg undertook the problem of determining the influence of variation of the extensive, intensive and temporal magnitude of stimulus on the time of reaction. In the work on duration he used only visual stimuli, but in the intensity work he used auditory stimuli also. The stimulus used in the visual work was daylight reflected from paper of varying degrees of brightness. His stimulation apparatus consisted essentially of a large iron wheel 92 cm. in diameter with a rim 17 cm. wide. This wheel was driven by an electric motor at a uniform speed of one revolution in three seconds. The author does not specify how this uniformity was obtained except to say that the speed of the motor was regulated by a resistance coil. It is so extremely difficult a task to obtain anything approaching perfect regularity of revolution by resistance control of a motor that it may perhaps be doubted, in the absence of evidence as to the speed of the wheel, whether it did more than approximate the speed mentioned. The stimulus paper was mounted on a rim, slightly projecting, so that its rate of movement was one hundred centimeters per second or one millimetre per sigma. Between the wheel and the reactor was a screen having an aperture of 16 x 16 cm. into

which smaller paper screens having apertures of from 3 to 48 mm. square were inserted. Except in two cases the back-ground was black. The stimulus paper, carried by the revolving wheel, moved past this aperture. The raising of a drop screen, which covered the aperture, about 1½ seconds before the exposure, furnished a warning signal. Reaction was made by means of an ordinary telegraph key, and the Hipp chronoscope was used for recording.

The experiments on intensity will be mentioned later. In the experiments on duration five strips of white baryta paper 48 mm., 24 mm., 12mm., 6 mm., and 3 mm. wide respectively were used for stimuli. Inasmuch as the speed at which these papers traveled was one mm. per sigma their exposure times were 48, 24, 12, 6 and 3 σ.

The intensity and the maximal size of stimulus were kept constant. The intensity was nominated 100, the size of the exposure was 3 mm. square. The average length of reactions by two reactors to each of Froeberg's five durations is given in the following table in sigma (σ). R. T. signifies reaction time and M. V. mean variation. Each value is the average of 400 reactions:

	48		24		12		6		3	
	RT	*MV*	*RT*	*MV*	*RT*	*MV*	*RT*	*MV*	*RT*	*MV*
Subj. R.	191.1	11.3	193.5	11.3	196.4	10.9	198.7	11.	200.6	12.1
Subj. W.	173.4	7.9	175.2	8.7	177.4	8.5	179.2	9.3	180.7	8.8

Froeberg's conclusions are to the effect that reaction time increases by approximately equal arithmetical increments as the duration of the stimulus decreases geometrically. This is held to be true only over a limited range, when the threshold is approached the increase becomes more rapid. The differences found by Froeberg are slight, and their interpretation not altogether unambiguous. It seemed imperative that the influence of duration should be thoroughly investigated anew.

My work on the problem of the influence of duration of stimulus on reaction time was done in the Psychological Laboratory of the Johns Hopkins University, under the direction of Dr. Dunlap, in the years 1910-1912. The problem was thoroughly

worked out for auditory and visual stimuli. Especial pains were taken to have accuracy of all measurements, to have the conditions uniform and easy for the reactors, and to have an adequate number and distribution of reactions. In the visual work 37,050 reactions were recorded, and in the auditory work about 12,000.

EXPLANATION OF PLATES

Plates I and X require no explanation beyond what is given in the text in describing the apparatus. In each case the broken lines represent reaction circuits, and the continuous lines represent the stimulus circuits.

The arrangement of the graphs is very simple. The abscissæ are indicated only once on a plate, but are the same for all graphs on a plate. They can be determined for any particular graph by means of a straight-edge from the graph in which they are indicated. They represent five sigma to a division, and every fifth division is denominated. The ordinates are not indicated, but are so chosen that the height from the base line of one graph to that of the graph above represents just 20% of the total number of reactions to that stimulus. By virtue of this arrangement all graphs are directly comparable, regardless of differences in the actual number of reactions made by the subjects.

The letter at the upper right hand corner of the plate represents the reactor, and the letter at the left hand side of each graph represents the stimulus. The small figures inserted at the right or left side of some of the graphs indicate the percentage of reactions the time of which would fall outside the graph at that end. For instance, in Plate II in the cases of both stimuli S5 and S4 there is .5 of 1% of the reactions below 70 sigma in length, and in the case of S2 there is .5 of 1% of the reactions above 220 sigma.

II. REACTIONS TO AUDITORY STIMULI OF VARYING DURATION

The arrangement of apparatus used in this part of the investigation is schematically represented in Plate I.

The stimulus used was a noise produced in a telephone receiver held to the ear of the subject by the usual operator's head piece. The phone was placed in parallel with an ordinary electric buzzer which was in the experimenter's room. The current operating this buzzer was kept constant at .17 amperes by means of a rheostat Rh 2 in parallel with it. Another rheostat Rh 1 was inserted in series with the whole stimulus circuit. This rheostate Rh 1 affected the amperage on the whole circuit, while rheostat Rh 2 primarily affected the current on the buzzer. This rheostat Rh 2 was fixed at a certain position where it produced what was judged to be a satisfactory tone in the receiver, and was carefully fastened so that it could not be moved from that position during the whole course of the experiment. This buzzer, of course, could not be heard by the subject except through the telephone. The mechanism for producing the stimulus did not start this buzzer, but merely completed and then broke the telephone circuit arranged in parallel with it. The arrangement of apparatus necessary to produce this effect will be described a little later. The buzzer was kept in operation during the whole course of the experiment. This is an important detail inasmuch as it requires a few sigma to get the buzzer in full operation. The duration of the stimulus was controlled by a Wundt Fall Hammer (large model, made by Zimmerman). The two rear keys set at different heights were used for this purpose.

The two sliding keys of the fall hammer were inserted in the circuit in such a way that the hammer in falling completed the circuit through the make-and-break key BCI (See Plate I) and a moment later broke it again by means of the simple break

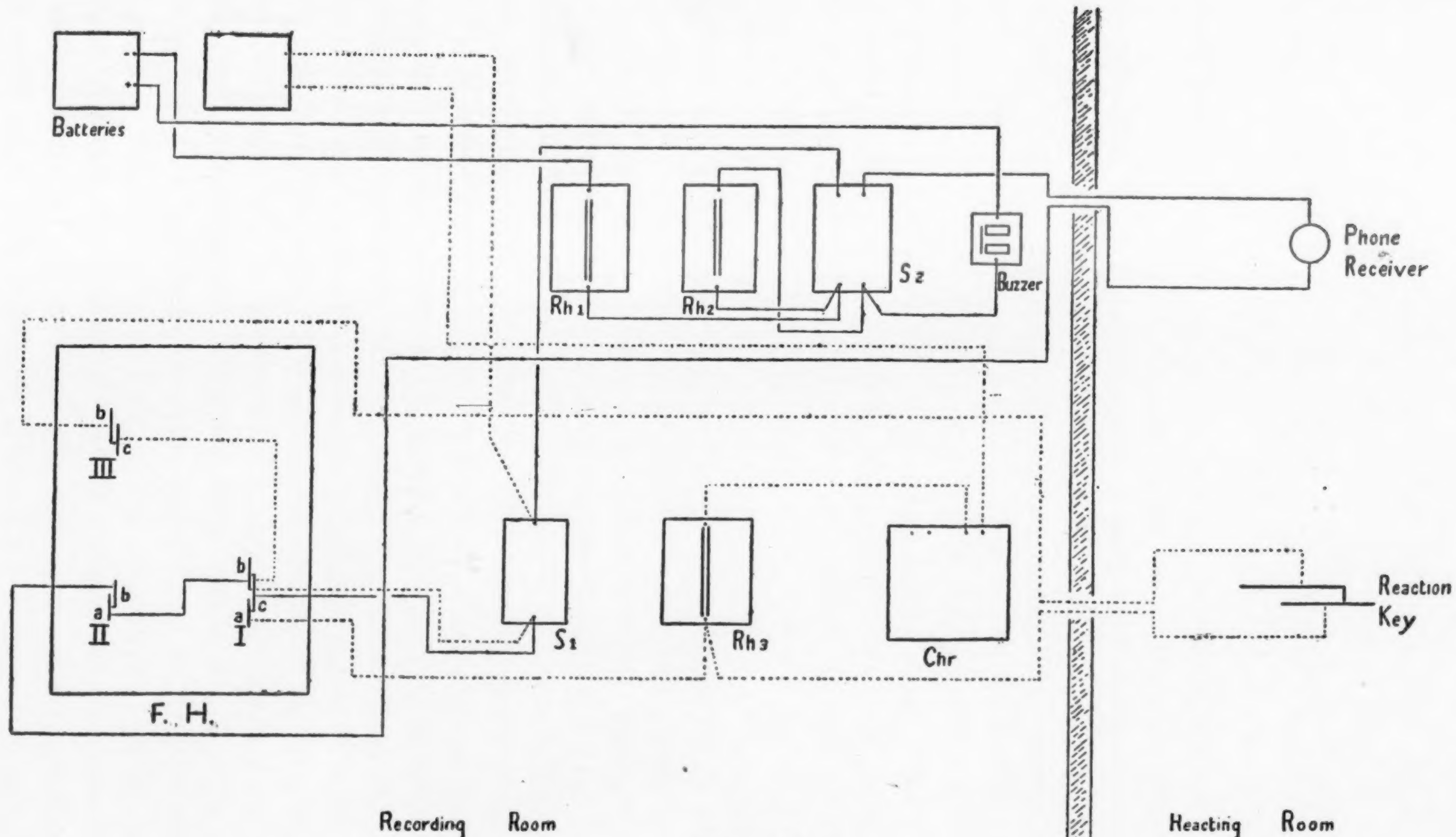

Batteries
Rh1
Rh2
S2
Buzzer
Phone Receiver
F. H.
b
c
III
a
b
II
b
c
a
I
S1
Rh3
Chr
Reaction Key
Recording Room
Heating Room

PLATE I

key BC II. The completion of the circuit in this way cut in the telephone so that the sound made by the buzzer, which was already in operation, could be heard by the subject. The breaking of the circuit cut the telephone out. Thus it can be seen that the length of time during which the buzzer could be heard was governed by the distance in height between the two rear keys. The counterpoise of the fall hammer was kept in a constant position throughout the experiment. Five positions for the two keys were chosen which gave intervals which seemed suitable for the purpose required. The durations of stimulus given by these five positions were measured by the spark chronograph method (two break sparks being used). The error of setting of the keys for any one of these durations was less than one sigma.

The recording instrument was a Hipp chronoscope, which was run from break to make. A constant current of .1 ampere was used on the chronoscope, measured daily and controlled by a rheostat, Rh 3.

The chronoscope circuit had two branches. In one was inserted the break contact of the upper moveable key of the fall hammer, and in the other the reactor's key and the make contact of one of the fixed fall hammer keys, BC III, which was kept closed, and hence out of function during reaction series. The chronoscope circuit was therefore broken at the instant of completing the stimulus circuit, and remade either by the reactor's key or by the lower fall hammer key. For control purposes the upper moveable key was set at a certain point, the reacting key was closed, thus completing the whole circuit, and a series of ten readings taken of the time of the drop from Key I to Key III. The variation of the chronoscope for a particular day having been ascertained corrections were made in the reaction results for that day. No attempts were made to modify the reading time of the chronoscope by adjustment of the springs or of current.

The control interval employed as measured by the spark chronograph was 115.6σ. The reacting room was separated

from the experimenter's room by two hallways and three doors. The sound of the running of the chronoscope and the falling of the hammer was not perceptible to the reactor. The reacting room, however, was not quite soundproof, and there was occasionally some slight disturbance owing to persons passing in the hall outside, to the banging of doors, etc. If disturbed by such occurrences while reacting the subject signalled the experimenter by the means described below, and the reading for that reaction was struck out of the final records.

A warning signal was arranged in the following manner: A 16 c.p. incandescent lamp was placed in the reacting room. About two seconds before the coming of the stimulus this light was turned out by a switch in the experimenter's room, and this extinguishing of the lamp served as the warning to the subject. In series with this lamp in the reacting room, there was placed in the recording room a sound hammer, and a group of three lamps in parallel. By this arrangement the three lamps in the recording room were dimly illuminated when the lamp in the reacting room was brightly illuminated. When the subject wished to communicate with the experimenter he short-circuited his lamp by means of a push button, and in so doing caused the sound hammer in the recording room to fall and the three lamps to flash out at their full brightness.

The sound hammer was not released until the current was completely cut off (in giving the following warning to the reactor) and hence served only to call the experimenter's attention to the reactor's signals; these signals therefore were interpreted by the number of flashes of which they consisted. One flash meant that some disturbance had distracted the subject's attention at the moment of reaction, two that the apparatus was not working well, and three flashes that the subject wished to speak to the experimenter. In the first part of the experiment a telephone whereby the experimenter could converse with the subject was included in the outfit, but was later abandoned, as it was used very little, and being connected to the 'phone which conveyed the stimulus to the subject's ear caused some trouble by a "humming" which was occasioned by induction.

The procedure to record a reaction was as follows: Key I. on the Fall-hammer having been placed at the correct height, the main switch SI. was closed (to avoid heating the coils of the chronoscope it was kept open except when an experiment was actually being made) the chronoscope mechanism was started, the warning signal was then transmitted to the subject's room, and about one and a half seconds later the hammer was dropped. In falling it first opened contact ACI, starting the chronoscope, and at the same instant closed contact BCI, cutting in the interrupter. Then the hammer hit Key II and opened contact ABII and by so doing cut out the interrupter. Upon the reactor's pressing the reacting key the chronoscope circuit was closed and the recording hands stopped. The chronoscope mechanism was then stopped, the reading was taken, and the whole procedure repeated.

The reacting key used in these experiments was the one described by Dr. Dunlap in the Psychological Review Monograph Supplements.[22]

The key was so adjusted that the slightest quick movement was sufficient to break the current through it, but so that the circuit would not be broken by the slower depression due to the weight of the hand. The actual weight required to depress the key was between 90 and 100 grams. A steady pressure of this weight did not break the contact.

1. *Reactions to Five Durations of Stimuli.*

Five subjects were used in this portion of the experiment. D. is Dr. Dunlap, W. is the only woman who took part, and was a wholely inexperienced reactor. U. and J. are graduate students in the department of Psychology of the Johns Hopkins University, and have had some experience in reaction work, but not very much. Wh. was a freshman in the College and entirely inexperienced in psychological work. D., of course, understood the problem thoroughly, and U. and J. had some idea of it. The other reactors were wholly in the dark as to the meaning of their work. It was impossible to perform the experiments at a uniform time of day, owing to conflicting calls on the subjects

of class and other duties. The reactions were obtained at such times as the reactors were free. A series of fifty reactions was taken at each sitting, ten to each length of stimuli. A short rest was then given after which fifty more reactions were made, the stimulus-durations being given this time in reverse order. Before recording any reactions several series were taken to get the subject into the proper mode of attention, and to accustom him to the general routine of reaction, and to the handling of the key.

Two sets of instructions were used, one emphasizing the sensory, and one the motor form of attention. A synopsis of these instructions was typewritten and handed to the subject and they were orally elaborated at the beginning of the series of experiments, and on various occasions thereafter until they were pretty thoroughly understood.

It was desired that some of the subjects should exercise sensory and some motor attention. D. J. and Wh. were instructed (1) in the interval between reactions to consciously foster the intention to press key as soon as stimulus appeared, such deliberate intention only being necessary during early part of experiment, as, later on, the fingers would perform their duty without any such attention being exercised even before the warning signal. (2) That from the very first the fingers must be absolutely neglected as soon as the warning was received, the entire attention being put on the expected stimulus. On the other hand W. and U. were instructed (1) during intervals between reactions to remember that the coming of the stimulus should be the signal for pressing the key. (2) As soon as the warning signal comes to neglect the stimulus entirely and think only of pressing key as rapidly as possible.

These instructions were fulfilled with great accuracy as soon as the subjects were entirely familiar with the process of reaction. Frequent inquiries as to attention were made during both the training series and the experimental series proper, and were continued until the experiment was finally completed.

Each subject had but one set of instructions given him, and

was never required to change from sensory to motor type, or *vice versa.*

The question of the type of attention of a subject is an important one. Lange[40] first stated that the reaction time is shorter if the attention is directed to the expected movement rather than to the expected stimulus.

Wundt[60] reports that the difference in the time of reacting under the two conditions of attention varies, in the case of reactions to sound from 89σ to 114σ, and in the case of reactions to light from 109σ to 118σ. Martius[43] agrees in substance. Titchener ("Text Book" p. 432) says that the range of variation in reaction time due to the type of attention is about 1/10 of the total sensory time and 1/12 of the total muscular time.

Külpe (Outlines, p. 408) agrees that the sensory reaction lasts about 1/10 longer than the muscular reaction.

Flournoy,[29, 30] Cattell[17] and Baldwin[6] refuse to agree that the sensory reaction *per se* is longer than the motor, Baldwin explaining the difference in time when it exists by the differentiation of mental types into visual, kinaesthetic-motor and visual-motor.

In the Johns Hopkins Laboratory the so-called sensory reactions with crude key and instructions, have been found in general to be longer than the motor.

We have called the kind of attention suggested by the first set of instructions given above "sensory". By some psychologists it would, perhaps, not be admitted that the attention they call for is "sensory" attention. But under these instructions the reaction time becomes very rapid,[25] the direction of attention is easy to maintain, and the whole reaction movement approaches an automatic form having few complexes and distractions. It would seem, therefore, that, given enough practice that reaction times under "sensory" and under "motor" attention approximate very closely.

A warning signal, described above, was sent about two seconds before the stimulus. The subjects were told that the interval between the warning and stimulus was not exactly two seconds

in every case, but would vary somewhat. This did away with rythmic reactions.

The five lengths of stimuli were produced as described above by varying the rear contact of the Wundt fall-hammer. They were carefully timed by the spark-chronograph method. They were respectively (S5) 7σ, (S4) 30σ, (S3) 51σ, (S2) 76σ (Si) 106σ in duration. The shortest was clearly perceptible as a single click, the others seemed to be not entirely homogeneous in their nature, that is, a slight variation in intensity was perceptible. The subjects were of the unanimous opinion that no difference in intensity was perceptible in passing from (S4) to (S3), to (S2), or to (S1), or in the reverse direction, but several of them claimed that there was a difference in intensity noticeable in passing from (S4) to (S5) or from (S5) to (S4). It may be objected that on this account *i.e.* because (S5) differed from the other stimuli in intensity as well as in duration, the reaction times to stimulus (S5) should be omitted from our final curves and tables. We have not so omitted them, although there may be some ground for the objection. However, the comparison of the results from (S5) with those from the other stimuli would seem to reveal no such disturbing factor. Stimulus (S4), 30σ, was the shortest stimulus which could be obtained which showed no decrease in intensity to any of the subjects.*

The experiment would have served most of its purposes if no shorter stimulus than this had been used. But for purposes of comparison it was deemed advisable to require all the subjects to react to a very much shorter stimulus.

D. gave, in all, 1000 reactions. These reactions are tabulated in Table I, being arranged as averages of sub-series of ten reactions each. That is to say that each value recorded in the table is not an actual reaction time, but is the average of ten

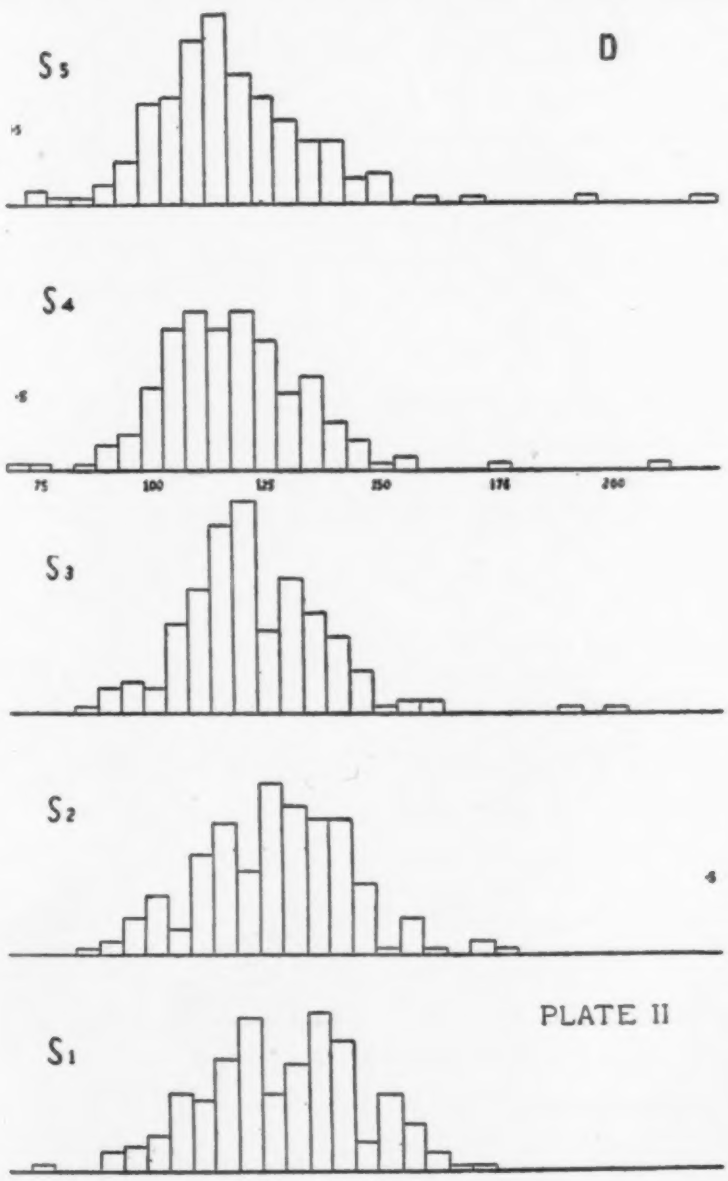
* This stimulus is shorter than the duration which it is usually declared is necessary for the sensation of tone to reach its full intensity. Sander[46] found .6 sec. was the minimal time for strong auditory stimuli to produce a sensation of full intensity. Kafka[37] working with weaker intensity found the time required to be even longer, namely, 1.5 sec.

reactions. This is the case with all other tables in the experiments with auditory stimuli.

The mean variation in each case is not the average deviation of the averages of these groups of ten from the general average, but the average of the deviations of the individual reactions from the general average. For this reason the M. V.'s cannot be verified from the tables here published, but only from the original full records.

In all cases the figures in the tables represent measurements in *sigma.*

The reactions of D. are graphically represented in Plate II.



The ordinates represent the numbers of reactions, and the abscissæ the length of reactions.

As we have said, D. was the only experienced reactor taking part in the experiment. His reaction times are small and the mean variations are steady.

W. gave in all 500 reactions, 100 to each length of stimulus. They were divided and recorded in tens as in the case of D. The M. V.'s were computed in the same way, namely, on the variations of the individual reaction times and not on the sets of tens. This method was followed in computing the M. V.'s for all subjects. W. reacted 100 times to each duration of stimulus. W.'s reaction times were large, extremely so, and varied enormously. Her M. V.'s accordingly are very large. The graphs of her reaction times are given in Plate III and the figures in Table II.

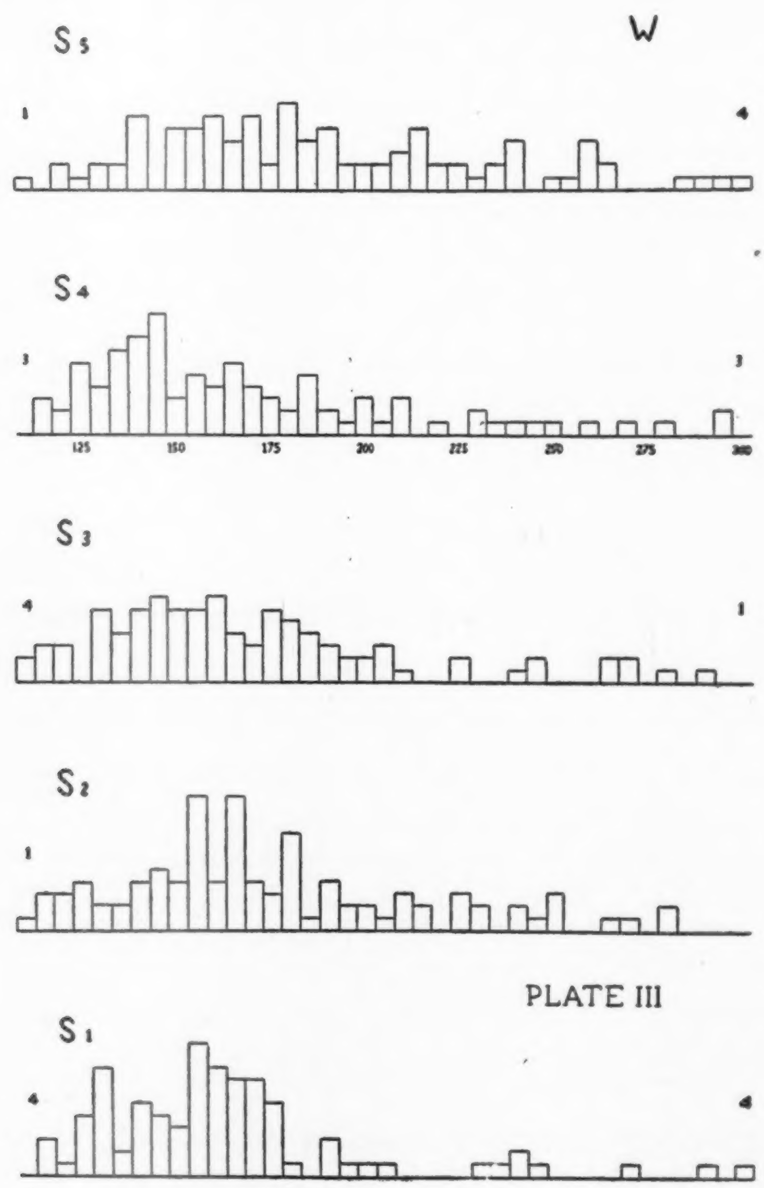


PLATE III

U. gave 250 reactions in all, evenly divided among the five stimuli. See Plate IV and Table III. His reaction times are

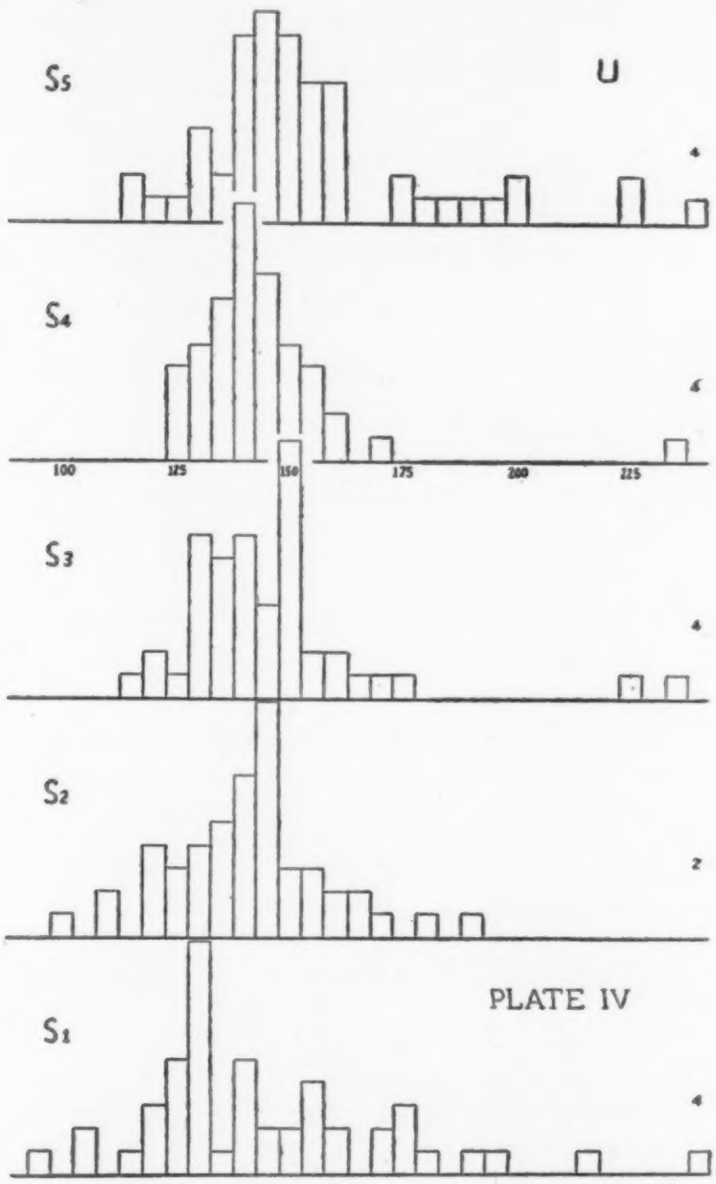


PLATE IV

quite long, and his M. V.'s in most cases large, but only moderately so in the cases of stimuli (S4) and (S2).

Two hundred and fifty reactions were obtained from J. His times also are moderately large, his M. V.'s, with the exception of those to stimulus I, being small, although not so small as in the case of D. See Plate V and Table IV.

Table V and Plate VI show figures and graphs of 1000 reactions from Wh. His reaction times are moderately short, while his M. V.'s are somewhat large.

These data show that three out of five subjects, namely, W., U. and J. take longer to react to stimulus (S5) than to any of

the other four. In the case of W. there is a difference of 6.1 σ between the most widely separated of her averages to the other four stimuli.

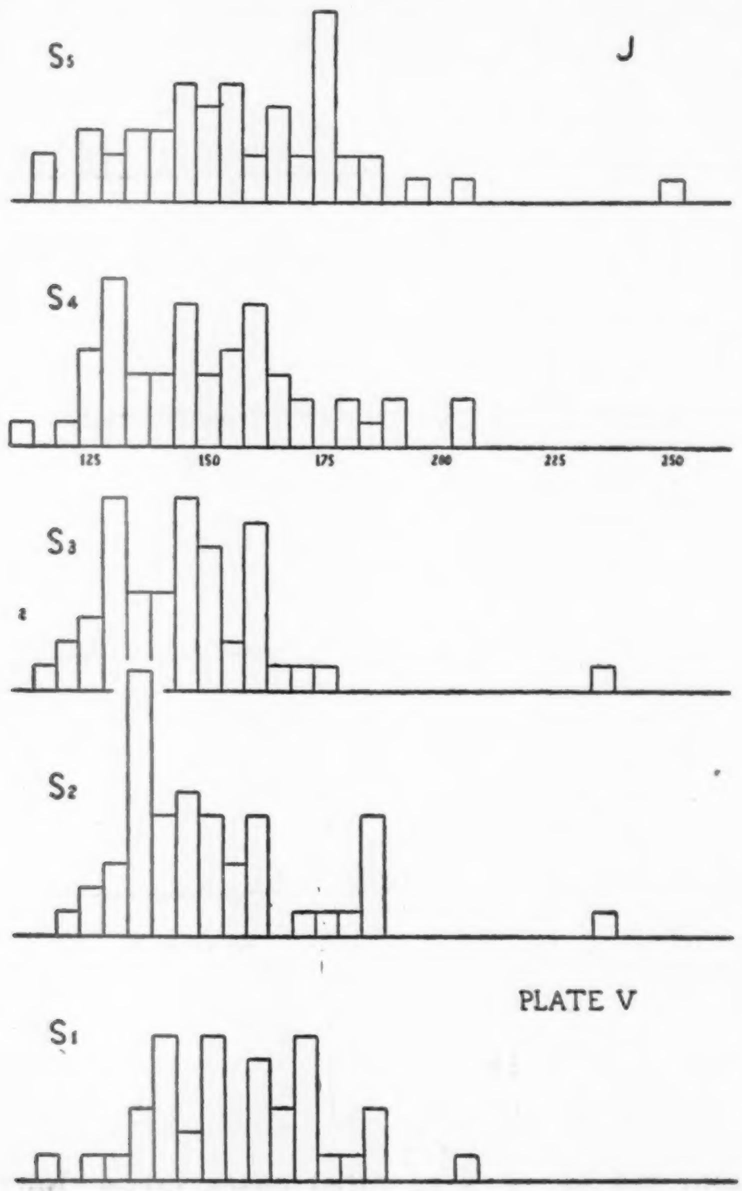


PLATE V

With U. the reactions to stimuli (S4), (S3), (S2), and (S1) are within 10.3σ of each other.

The averages of D. vary maximally by 9.1σ.J. shows a slightly wider divergence, there being a difference of 14.8σ between (S5) and (S3), (S3) being the shortest of all. The averages which Wh. gives differ by 8.7σ: In none of these cases is there a progressive increase or decrease of reaction time as the subject passes from stimulus to stimulus. In the opinion of the writer the differences noted are practically insignificant. There is greater disparity between reaction-times in every column of the

tables than between the averages of those columns. The likeness of the total average reaction times to each other is clear. These data demonstrate that when intensity difference is not present the duration of an auditory stimulus does not materially affect the time of reaction.

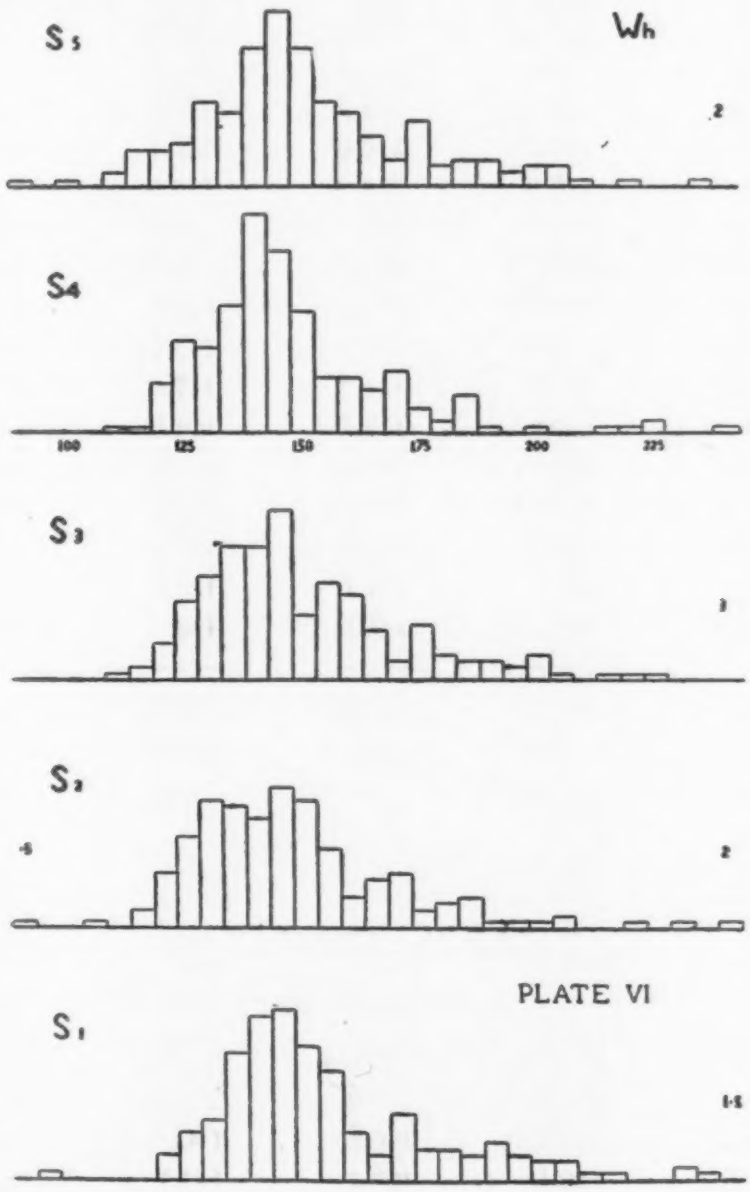


PLATE VI

TABLE I. SUBJECT D

1000 Reactions

	S1 106σ	S2 76σ	S3 51σ	S4 30σ	S5 7σ
	118.1	120.7	134.9	118.2	127.8
	135.6	134.1	137.8	133.5	107.6
	135.1	135.3	134.3	142.1	147.2
	136.6	132.1	125.3	121.8	125.8
	140.1	133.2	130.4	132.4	138.0
	132.0	139.9	123.3	125.7	127.2
	144.4	145.1	141.7	135.6	129.4
	122.4	118.7	119.0	116.1	118.6
	119.3	116.9	115.3	113.0	109.2
	115.1	114.4	109.6	106.5	112.2
	112.2	116.1	110.8	113.9	110.4
	110.3	108.8	113.5	108.4	110.8
	110.6	109.2	99.0	113.6	111.1
	133.8	131.2	121.3	117.0	109.4
	137.2	130.2	117.7	101.9	125.2
	115.4	126.1	119.0	111.6	114.6
	118.7	115.9	108.9	109.6	110.2
	147.9	138.5	132.3	125.5	116.6
	155.7	143.6	141.1	118.2	119.6
	139.6	137.4	138.5	134.2	135.6
Average	129.0	127.3	123.6	119.9	120.3
M. V.	13.7	12.07	12.1	12.4	12.7

TABLE II. SUBJECT W

500 Reactions

	S1 106σ	S2 76σ	S3 51σ	S4 30σ	S5 7σ
	163.9	223.7	197.6	253.5	280.1
	216.4	212.6	169.8	186.7	231.3
	215.8	159.1	168.1	147.7	235.0
	182.3	202.7	230.1	209.2	182.4
	147.5	156.3	143.8	151.2	158.4
	140.8	130.1	127.9	146.4	140.3
	160.5	179.9	174.2	168.3	183.2
	167.1	168.2	156.1	150.8	174.0
	140.3	161.5	170.4	162.3	201.4
	158.8	160.7	164.9	148.4	188.1
Average	169.3	175.4	170.2	172.4	197.4
M. V.	33.8	31.0	33.6	36.5	42.9

TABLE III. SUBJECT U

250 Reactions

	S1 106σ	S2 76σ	S3 51σ	S4 30σ	S5 7σ
	125.6	139.5	163.0	148.7	156.2
	158.3	163.8	168.6	139.8	168.6
	130.1	128.9	135.5	148.1	166.2
	148.4	144.9	153.6	158.3	159.7
	196.8	147.7	155.2	158.8	157.3
Average	151.9	144.9	155.2	150.7	161.6
M. V.	26.8	14.7	20.0	15.9	21.3

TABLE IV. SUBJECT J

250 Reactions

	S1 106σ	S2 76σ	S3 51σ	S4 30σ	S5 7σ
	172.5	171.7	158.4	157.3	150.4
	169.8	164.6	164.6	172.6	180.1
	143.7	144.7	134.6	161.6	168.3
	150.6	142.3	136.4	135.6	163.6
	154.0	141.3	132.7	138.5	138.0
Average	158.1	152.9	145.3	153.1	160.1
M. V.	13.	16.2	14.8	17.2	19.3

TABLE V. SUBJECT Wh

1000 Reactions

	S1 106σ	S2 76σ	S3 51σ	S4 30σ	S5 7σ
	167.9	163.7	169.2	146.1	149.4
	194.5	187.2	195.4	162.9	199.1
	163.6	143.9	181.0	154.9	154.0
	155.3	147.5	145.2	146.6	171.5
	156.8	149.1	189.2	156.5	161.6
	183.7	145.2	150.8	148.6	151.1
	188.0	166.3	136.4	167.2	168.3
	145.9	129.7	157.8	154.2	149.7
	144.2	140.3	147.7	139.6	157.6
	143.6	151.2	149.3	131.8	149.7
	146.2	151.4	149.4	141.7	159.1
	166.7	143.7	132.5	133.5	135.2
	142.8	134.1	135.6	156.8	149.0
	144.9	157.0	151.4	159.5	159.5
	163.5	153.5	152.9	154.0	150.4
	153.0	147.4	151.3	148.1	147.1
	144.2	142.3	141.6	131.8	143.1
	146.2	144.9	150.0	143.6	144.4
	138.2	137.6	136.2	139.0	156.2
	162.5	149.5	164.0	160.3	170.2
Average	157.5	149.2	154.3	148.8	156.3
M. V.	19.03	17.7	20.29	14.05	20.00

2. *Reactions to Auditory Stimuli of Varying Durations, with Previous Training in Reacting of those Stimuli*

In part 1 of this experiment the subjects before making any reactions to be recorded, underwent a period of training in reacting to all five durations, and, as just stated, their reaction-times for the four longer stimuli show no uniform differences under these conditions. The next step was to find out whether or not if they were trained to react to a stimulus of a certain length they would subsequently react in the same manner to stimuli of other lengths. Two series of experiments were performed to settle this point. In the first series two men were trained to react to one stimulus, and then were made to react to all five stimuli. In the second series two subjects were trained to react to a certain stimulus and later reacted to one other stimulus of different length.

A. ***Previous training to one length of stimulus and reacting to all five durations of stimuli.***

The subjects, two in number, were given a somewhat lengthy training to a particular stimulus duration. When their reacting had become more or less easy and steady they were presented with stimuli of five lengths, exactly as in Experiment 1. The stimulus durations employed were the same as in Experiment 1.

Two subjects were used here, We. and Do., both under-graduates in the Johns Hopkins University, neither were previously practiced reactors. We. was trained with 600 reactions to stimulus S1 (106σ).*

His averages and the M. V. for the 600 reactions, arranged in groups of ten each and averaged by hundreds are given in Table VI. The graph plotted from these results is given in Plate VII.

We was next given a series of the five lengths of stimuli arranged exactly as in Experiment 1. He reacted 80 times to each

* In the case of both We. and Do. and in the cases in Experiment 2B following the number of "training" reactions does not include some preliminary trials in which the subject made himself familiar with the working of the key, and the general process of reacting. These preliminary trials consumed a day or two. No record was taken of them.

length of stimuli or 400 times in all. These average and mean variations are given in Table VII and the graphs plotted from the series in Plate VII.

Do., was trained with stimulus S4 (30σ). He reacted 400 times and his averages with M. V. are given in Table VIII. See Plate VIII for the graph plotted from these figures. He was

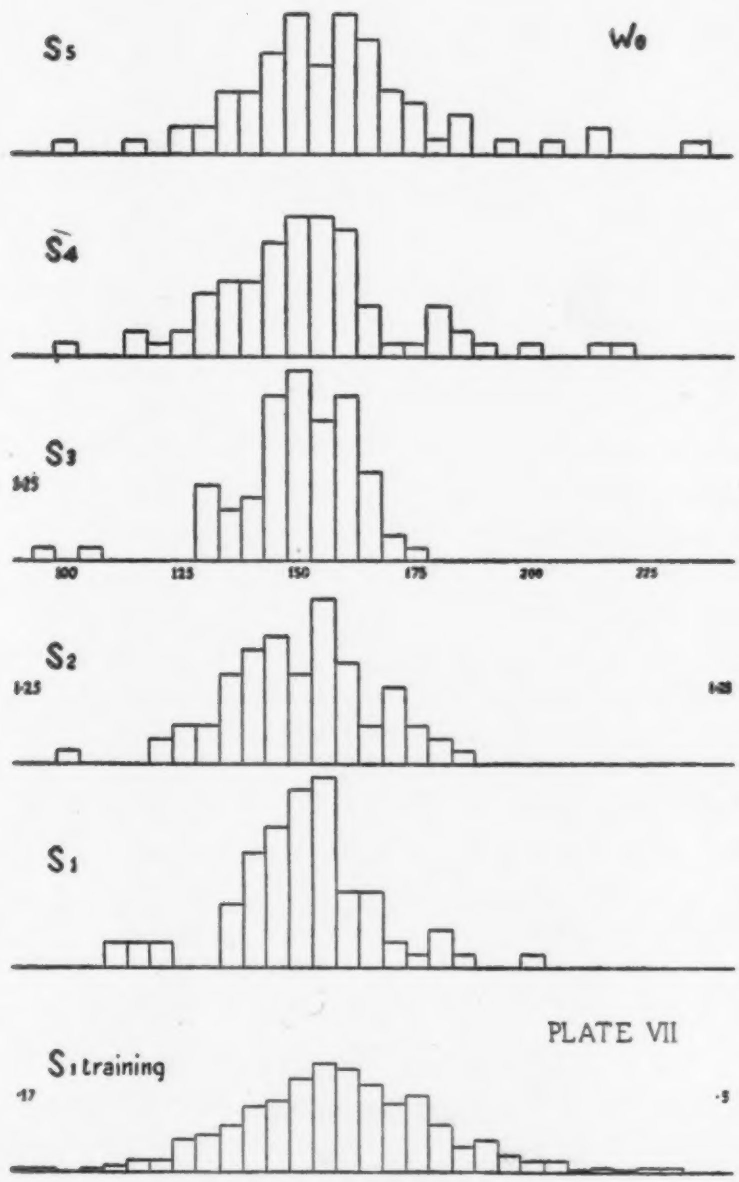


PLATE VII

then presented with the five lengths of stimuli in sets of ten each, 110 reactions to each duration, 550 in all, precisely as was done to the subjects in Experiment 1, and to We. in this Experiment. See Table IX and Plate VIII for the averages and graph.

TABLE VI. SUBJECT We

Stimulus S1 106σ 600 Reactions

		161.4	
170.5		158.4	
193.6		156.5	
191.3		153.9	
188.		150.7	
164.1		151.8	
162.2		157.5	
163.8		152.6	
162.3		152.7	
176.3		152.1	154
178.8	175	159.7	
177.5		151.2	
187.		157.9	
173.6		151.	
175.6		143.6	
182.7		148.4	
172.4		143.8	
168.5		149.4	
165.5		160.6	
174.5		145.7	151
174.4	175	138.6	
163.4		133.2	
165.		144.7	
158.9		145.2	
166.3		149.2	
166.2		158.5	
187.4		142.5	
158.2		137.5	
186.		140.	
157.		142.6	143
173.9	168		
	Average	161.	
	M. V.	16.7	

TABLE VII. SUBJECT We

400 Reactions

	S1 106σ	S2 76σ	S3 51σ	S4 30σ	S5 7σ
	142.5	134.8	144.3	145.5	147.1
	147.9	151.9	149.7	155.	156.3
	146.9	148.4	148.1	140.	156.8
	154.4	151.4	146.	160.	175.2
	146.	149.9	147.6	143.3	164.
	162.	159.6	160.	162.1	179.8
	153.2	172.6	151.2	151.9	148.7
	162.2	158.4	159.7	163.6	152.3
Average	151.9	153.4	150.8	152.7	160.05
M. V.	11.6	14.0	10.3	14.9	15.0

TABLE VIII. SUBJECT Do

Stimulus S4 30σ 400 Reactions

154.2		182.4	
148.6		171.7	
148.3		176.7	
156.8		188.5	
173.4		182.6	
159.8		177.3	
162.4		183.2	
189.6		165.9	
203.2		160.9	
179.5	167	178.9	176
184.4		144.7	
184.7		133.3	
181.6		142.9	
174.5		145.	
171.2		157.4	
171.5		152.0	
190.1		164.4	
182.5		160.5	
198.5		153.4	
184.9	182	148.8	150
	Average	168.75	
	M. V.	19.5	

TABLE IX. SUBJECT Do

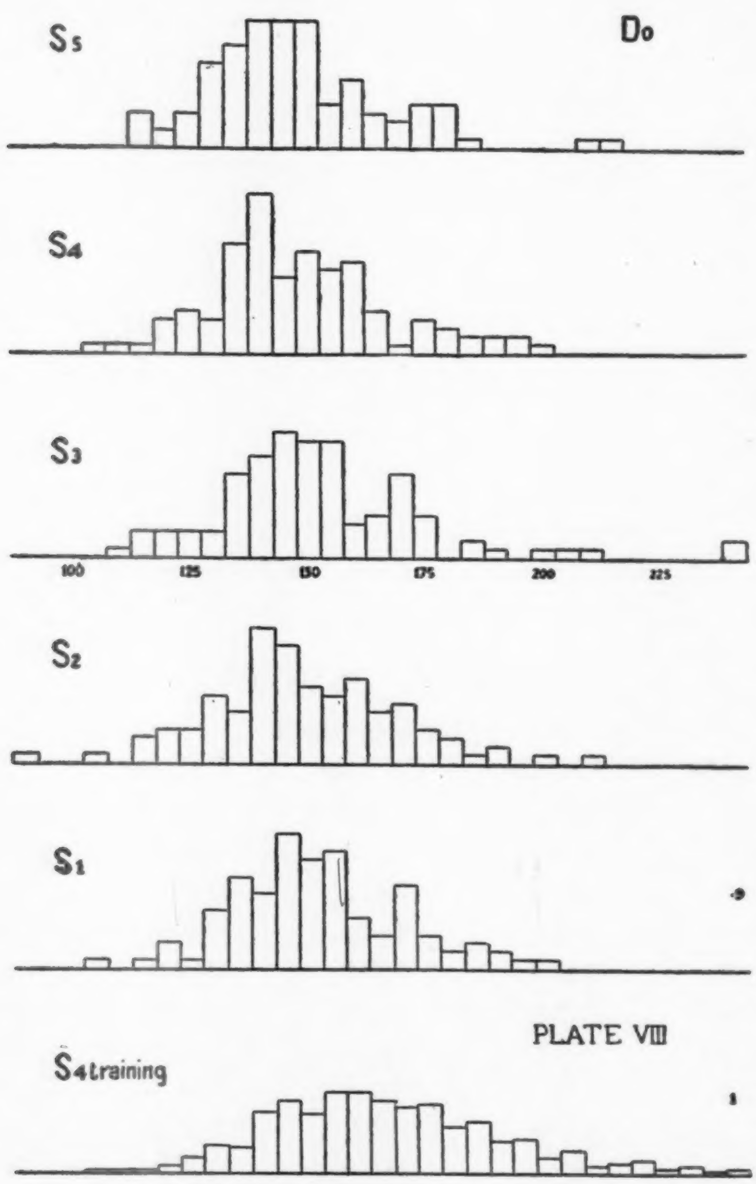
550 Reactions

	S1 106σ	S2 76σ	S3 51σ	S4 30σ	S5 7σ
	174.7	147.5	151.5	143.5	138.
	146.2	136.3	140.1	140.8	160.6
	152.3	152.2	149.4	158.	147.7
	148.2	159.1	144.3	140.1	140.6
	147.9	144.1	156.7	154.2	155.7
	156.4	159.5	149.9	152.4	154.2
	152.9	161.9	149.	141.9	143.8
	143.4	145.4	167.2	145.4	139.1
	155.3	150.2	158.6	155.3	150.3
	173.1	166.5	156.2	168.8	160.4
	154.1	162.	179.2	169.5	164.6
Average	154.8	153.1	154.7	151.8	150.5
M. V.	14.8	17.5	15.7	14.5	13.8

It may be seen from these results that there is no significant effect of varying the stimulation-duration, even when the subject has been lengthily trained in reacting to one duration.

B. *Previous training in reacting to one length of stimulus and subsequent reacting to one stimulus differing greatly in length from the one used in the training.*

Two subjects were each trained in reacting to one length of stimulus exactly as in A of this experiment. The same two stimuli durations were chosen. After the training period a series of



reactions was taken to a single stimulus differing in length from the one used in the training process.

The first subject, G., is a graduate student in the department of Philosophy, having had a small amount of experience in psychological experimentation. He was trained to react to the longest of the five stimuli which had been used in experiment 1, namely

stimulus S1 (106σ). His average for 450 reactions was 151.7σ with M. V. of 14.7σ. He then reacted 450 times to stimulus S4 (30σ). The average here was 154.4σ. These averages are gathered together in Table X. The graphs for these two series are inserted for purposes of comparison in one plate, namely Plate IX.

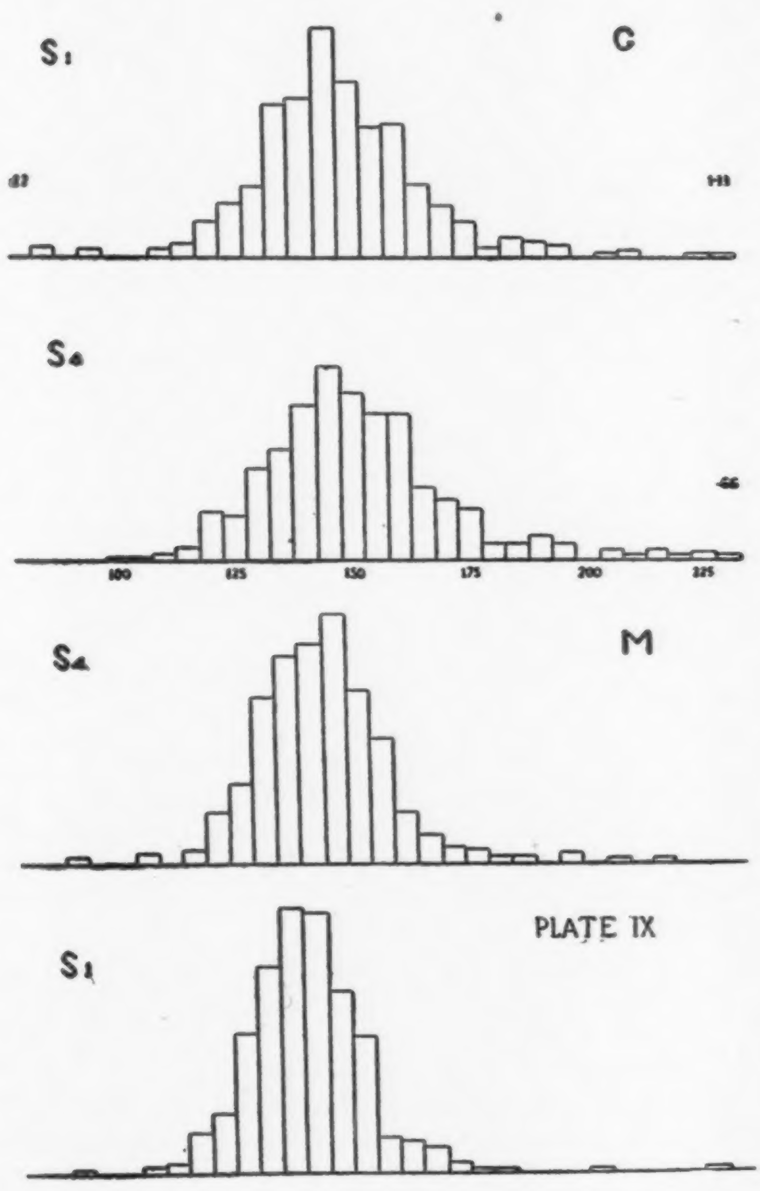


PLATE IX

TABLE X. SUBJECT G

450 Reactions Stimulus S1 106σ	450 Reactions Stimulus S4 30σ
158.7	168.3
154.8	143.4
153.9	158.4
147.4	161.0
139.6	151.2
149.2	163.0
145.7	145.6
141.1	149.3
142.1	146.0
142.6	147.0
156.3	157.5
151.7	144.6
133.5	153.6
148.2	162.4
146.3	172.5
141.1	162.8
139.9	157.1
132.9	167.3
141.5	159.8
152.8	162.6
168.3	150.7
170.5	153.9
153.6	155.7
157.9	151.6
150.6	158.1
171.4	169.3
151.1	155.0
151.8	147.7
167.0	151.5
158.9	157.9
166.0	164.2
149.3	149.6
140.1	147.0
154.5	141.7
142.6	149.0
156.4	152.5
157.2	141.0
156.5	163.6
152.3	164.1
155.4	148.2
143.6	149.5
161.8	151.0
166.3	149.0
153.9	133.3
150.1	152.2
Average 151.7	Average 154.4
M. V. 14.7	M. V. 15.2

TABLE XI. SUBJECT M

450 Reactions Stimulus S1 106σ	450 Reactions Stimulus S4 30σ
145.6	143.5
158.2	139.9
151.7	135.8
142.5	144.6
151.2	149.1
137.7	152.5
131.8	158.4
131.6	145.6
139.9	149.7
138.3	153.7
139.4	154.2
136.2	138.8
130.2	144.0
136.8	146.3
135.7	142.1
138.1	150.2
144.8	140.1
153.4	140.2
147.2	132.5
142.0	134.6
146.6	144.2
146.6	142.3
145.6	129.5
142.8	141.1
141.0	128.9
146.7	152.0
144.8	153.9
136.9	142.7
132.6	143.8
130.0	138.7
139.3	153.8
142.4	147.9
130.4	147.6
157.5	130.4
134.7	132.5
131.3	151.7
135.7	151.5
136.4	142.8
138.2	155.9
134.0	145.1
136.2	149.2
133.0	157.2
148.1	145.9
145.1	143.9
134.2	139.0
Average 140.4	Average 144.6
M. V. 9.08	M. V. 10.4

The second subject, M., is a graduate student in Biology, with no experience whatever in psychological experimentation. He was trained first in reacting to stimulus S4 (30σ). Here his average reaction time for 450 reactions was 144.6σ and the M. V. 10.4σ. Then 450 reactions to stimulus S1 (106σ) followed, giving an average of 140.4σ with M. V. of 9.08σ. See Table XI and Plate IX.

The results of these tests show that the subjects reacting in a long set of experiments to stimuli of 30σ duration and then to stimuli of 106σ duration, or vice versa, react in practically the same way to both durations.

Table XII is inserted as a convenient summary of the results of the entire series with auditory stimuli.

TABLE XII

		S1 106σ		S2 76σ		S3 51σ		S4 30σ		S5 7σ	
		R.T.	M.V.	R.T.	M.V.	R.T.	M.V.	R.T.	M.V.	R.T.	M.V.
D......	200	129.	13.7	127.3	12.	123.6	12.1	119.9	12.4	120.3	12.7
W......	100	169.3	33.8	175.4	31.	170.2	33.6	172.4	36.5	197.4	42.9
U......	50	151.9	26.8	144.9	14.7	155.2	20.	150.7	15.9	161.6	21.3
J.......	50	158.1	13.	152.9	16.2	145.3	14.8	153.1	17.2	160.1	19.3
Wh.....	200	157.5	19.	149.2	17.7	154.3	20.3	148.8	14.05	156.3	20.
We....	600	161.	16.7	(Training)							
	80	151.9	11.6	153.4	14.	150.8	10.3	152.7	14.9	160.	15.
Do.....	400							168.7	19.5	(Training)	
	110	154.8	14.8	153.1	17.5	154.7	15.7	151.8	14.5	150.5	13.8
G.......	450	151.7	14.7	(Training)							
	450							154.4	15.2		
M......	450							144.6	10.4		
	450	140.4	9.08	(Training)							

III. REACTIONS TO VISUAL STIMULI OF VARYING DURATION

After the completion of the work with auditory stimuli two series of experiments were made with different lengths of visual stimuli. In one series the stimuli used were five durations of illumination preceded and followed by darkness; the stimuli of second series consisted of five durations of darkness, of approximately the same lengths as the times of appearance, preceded and followed by illumination. These stimuli will be referred to below, in the cases of the occlusion or limited darkening of the light as A1, A2, A3, A4, A5 and in the cases of the presentation of the light as B1, B2, B3, B4, B5. A1 and B1 were what may be called total occlusion and total presentation, that is to say, in these cases the light was respectively presented or occluded for a length of time very much longer than any simple reaction time. The length of A1 and B1 was one second, just half the period of the pendulum. The other stimulus lengths, carefully measured by a drum chronograph with 250 d.v. fork and a Pfeil marker were in sigma, A2, 150; A3, 66; A4, 31; A5, 10; B2, 144; B3, 64; B4, 25 and B5, 12.

The source of illumination was a Nernst filament mounted in the lamp-box of a projection lantern. The filament was started by means of a small gas flame. The lantern lenses were so arranged that an image of this filament was focused at a point 167 centimetres from the filament, and 70 centimetres from the front lens of the lantern. The pendulum, which has been described by Dr. Dunlap,[26] was placed so that the image was focused on the screen carried above the knife edges. Beyond the screen, when it was removed, the diverging rays were projected upon a plaster of paris disc 9 cm. in diameter, placed 162.4 cm. from the screen and 232.4 cm. from the front lens of the lantern. The background surrounding the disc was of black velvet, which absorbed all rays falling upon it. The room was dark

and a large screen was placed between the subject and the pendulum, cutting off the faint illumination from the image on the pendulum screen so that the illuminated disc shone out very brightly. It can be seen that a screen cut with edges on radii from the knife edges would occlude the light from the disc for a period of time which is a function of the width of the sector, the time of swing of the pendulum being constant. Five such screens were used for the A series (the occlusion of the light). For the B series, in which the light was exposed, five screens were used with apertures cut on radial lines. These screens in all cases but one were made of cardboard. In that one case, A5, a very narrow sector was required, and to prevent any chance of its being broken it was made of aluminum.

The subject was seated beside the pendulum about two metres from it. As has been said, a screen was placed between him and the pendulum and lantern. The distance from the eye of the subject to the disc was about three metres. No head rest was used and this measurement is therefore only an approximation, the variations from it being, however, small and negligible. The plane of the disc was not exactly perpendicular to the axis of the light, but was turned slightly toward the reactor. The disc was really a circle of 9 cm. diameter but as seen by the subject was an oval 9 cm. high and about 8 cm. wide.

The retinal image of the plaster disc for the normal eye at the distance given is about .4 mm., according to the simple formula A: B:: a:b, A being size of object, B size of retinal image, a, being distance of object from nodal point of eye, and b, distance of retina from nodal point. According to Howell ("Physiology" p. 306) b equals 15.5 mm. Since the diameter of the fovea is approximately .341 mm. (Howell "Physiology" p. 307) with exact fixation the whole fovea would be covered. Slight divergence in fixation would stimulate a considerable foveal area, and some portion of the extra foveal macula. This probably provides the most nearly uniform stimulation which can be secured.

The subject used both eyes, and as the disc was about 45 cm. above the level of the eye, his gaze was slightly upward.

In using the Nernst glower as a source of illumination two points must be kept in mind if its luminosity is to be maintained constant. In the first place the illuminating efficiency of the Nernst varies considerably according to the length of time it has been used. Yerkes and Watson[62] report that the life of a Nernst glower is six hundred hours on direct current and eight hundred hours for alternating current, regardless of position.

During the first two or three hundred hours the intensity of the light diminishes rapidly as much as ten or fifteen per cent. Then follows a period during which the intensity of the light remains practically constant.

In our experiment a new glower was allowed to burn for several hours before being used to produce the stimulus light.

The illumination at the point at which the disc was in the beam of light was carefully determined by the Lümmer-Brodhun photometer, and was equal to that of a 3¼ c.p. lamp at a distance of 142.5 cm. This measurement is within 2% of exact accuracy. The intensity was kept constant by the following procedure.

Between the sector or focus of the rays and the disc a Lümmer-Brodhun photometer and a small standardized incandescent lamp were placed. These two pieces of apparatus were carefully adjusted so that the illuminations of the standardized lamp and of the stimulus light exactly balanced. They were fixed in position so that they did not vary laterally, but could be lowered out of the path of the light during reaction experiments, and returned to the position for controlling the intensity at any time. The photometer so used did not give a measure of the intensity, but simply a means of keeping it constant.

The second point to be kept in mind is that to maintain a constant luminosity on the Nernst filament it is necessary to maintain a constant current supply. The characteristics of the Nernst glower as a pyroelectrolytic conductor are such that constant voltage at the glower terminals does not insure even approximately constant illumination. (Steinmetz.[53]) Therefore it is necessary to control the amperage accurately. The

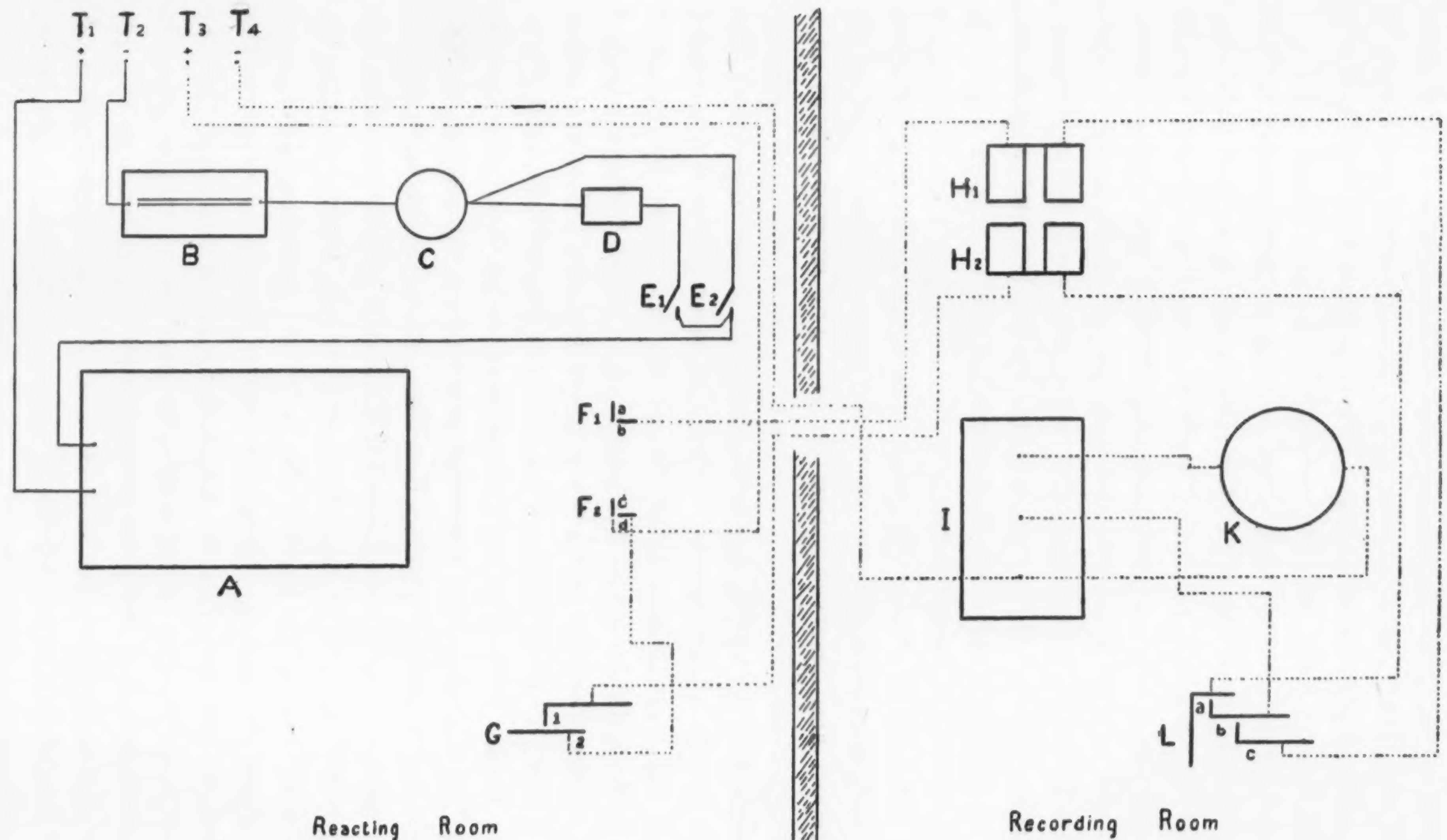
current through the Nernst glower which we used was controlled by a rheostat, and an ammeter was kept so that it could be switched into series with the glower. The amperage necessary to keep the light up to its normal intensity varied from .6 amperes to about .65 amperes. The test with the photometer was made at frequent intervals, the ammeter reading was taken several times during each working period. In this way a complete check was obtained on the intensity of the stimulus light.

The lantern, exposing apparatus and the subject were in one room, the recording apparatus and experimenter in another.

Plate X represents schematically the apparatus for producing the light, the reaction key and the apparatus for registering the reaction time. The photometer and control lamp are not shown.

A represents the lantern, B and C respectively are the rheostat and ballast for controlling the Nernst filament. D is the ammeter and E1 and E2 are switches by means of which the ammeter may be cut in or cut out of the circuit. F1 and F2 represent the two contacts on the scale of the pendulum. These contacts are actuated by a permanent magnet on the swinging arm of the pendulum. In F1 is also a permanent magnet but of less strength than that on the swinging arm. Thus a and b were always kept in contact except when the pendulum swung over them. Immediately after the pendulum has passed over a and in so doing has broken the contact ab the contact is re-established. The time necessary for the re-establishing of this contact was about 25σ. F2 was used only for checking purposes and at other times was slid entirely beyond the reach of the pendulum magnet. In F2 c, d were always kept in contact while recording reactions. H1 and H2 are the upper and lower magnets of the Hipp chronoscope which was used for the recording. The chronoscope was used without springs in the manner adopted in the Johns Hopkins laboratory.[24]

The circuit as represented in Plate X goes from the terminal T, to F2, where it divides. One branch goes to F1, thence to the upper magnets of the chronoscope H1, to the control key L, to the double throw switch 1 and back to the terminal T4. The



T1 T2 T3 T4
B
C
D
E1 E2
A
F1 a b
F2 c d
G 1 2
H1
H2
I
K
L a b c
Reacting Room
Recording Room

PLATE X

other branch goes from F2 to the reaction key G, to the lower chronoscope magnets H2, thence to control key L, to switch 1, and back to the terminal T4. The current which divides at F2 unites again at the key L.

The pendulum was held deflected by an electro-magnet and was released by a switch in the experimenting room. The diagram does not represent this switch. The circuit used was the direct current 118 volt power circuit, and was kept constant at .17 amperes.

The reaction switch G is the same one used in the auditory experimentation. It was kept closed at G1 G2, and was broken by the slightest decisive movement of the reactor's finger in the manner described above.

The control key L is one which has been used by Dr. Dunlap and myself in earlier reaction work[25] but was not described in our report and deserves a few words. The lever b moves on a fixed pivot and the lever c moves on a pivot attached to b, enabling the operator by a slight pressure of his finger to make c and b come into contact and by a greater pressure to bring b and a also into contact. Both levers are held down by the same spring (not shown), and by means of a second spring, not used in this experiment, a more complicated action of the levers may be obtained. It has been said that the current which split at F2 unites at L. This main current returns to the terminals from b. Thus it can be seen that when the experimenter presses his finger on this key he makes contact first between bc which actuates the upper magnet. This moves the armature of the chronoscope up, putting the hands out of action. When ba come into contact the armature remains against the upper magnet until the current through it be broken, when the armature moves over to the lower magnet. The current through the upper magnet is broken when the pendulum is dropped, the permanent magnet on the pendulum breaking the circuit through ab. This current through ab is re-established in the manner described above, but not until after the armature of the chronoscope has moved to the lower magnets. The current through these lower magnets is broken

by the reacting movement of the subject so that the armature immediately moves back to the upper magnets and the recording hands stop. This method of operating the Hipp chronoscope has been found extremely satisfactory.

For checking purposes F2 was placed at a determined place on the dial of the pendulum, the reaction key being kept closed. This arrangement provided that the swinging pendulum first broke ab and then cd. The breaking of the circuit at cd acted exactly as the breaking of the circuit by the reaction key at G. The duration of the swing of the pendulum between F1 and F2 was determined by the spark chronoscope, the period used for checking being 158.75σ. The error of setting of F2 was below 1σ, and the chronoscope averages from day to day never varied more than 5σ, and seldom as much as 3σ. This variation was doubtless due to effects of temperature on pendulum and chronoscope. The mean variations of the chronoscope readings were on every day less than 1σ.

The warning system consisted of a buzzer in the subject's room and a sound hammer in the experimenter's room. This, for simplicity's sake, is not represented in the diagram. A key in the experimenter's room and a switch in the subject's room were connected with the buzzer and the sounding hammer by a three-wire system which enabled either experimenter or subject to signal to the other.

The process of reaction was as follows: The glower having been put in operation and the subject's eyes having adapted to the darkness, the experimenter closed Key 1, started the chronoscope mechanism and sent a warning signal to the subject. About a second and a half later the switch which dropped the pendulum was broken. The pendulum took half a second to swing to the lowest point of its arc, at which place the exposure (or occlusion) of the light was effected. Thus the interval between the warning and the stimulus was about two seconds. The moment of exposure was, of course, the moment at which the chronoscope hands began to run. Immediately after the subject reacted the experimenter lifted his finger from the key L, thus

breaking the current through the whole system and preventing the back swing of the pendulum from again starting the chronoscope hands. The pendulum was caught by the electro-magnet on its return swing.

The chronoscope was then stopped, the reading recorded and the operation as a whole repeated.

Eight subjects were used in this investigation. With two exceptions they were previously inexperienced reactors. In all cases they were given a lengthy series of reactions before any were recorded. This training series lasted in some cases about two weeks and was continued until any practice effect in future reactions was eliminated. It was planned to have each of the eight men react five hundred times to each of the ten stimuli. This program was carried out in six cases. In one case it had to be curtailed because of sickness, and in another for less excusable reasons for absence on the part of the subject. In both of these cases, when it was seen that the entire program could not be completed, it was thought advisable to have the subjects react to each stimulus a fewer number of times rather than to omit entirely the reactions to any one particular stimulus. Accordingly they reacted only two hundred times to several durations of stimuli.

It was not possible to have any particular time of day for experimenting. The work was carried on whenever the subjects could arrange to act. In some cases it was as early as eight in the morning and in others as late as four in the afternoon. In fact the work of experimentation was in progress for a period of some months during practically all of every day.

The reactions were taken in sets of fifty. The subjects were given a short rest after every fifty reactions. As a rule one hundred and fifty reactions were taken at a time, in a few cases two hundred were taken; never more.

The instructions to the subjects were very carefully considered. In order not to confuse two problems it was decided to have all instructed alike, and it was also decided to instruct all to react with "sensory" attention. Inasmuch as the problem

was to determine the influence of sensible differences on reaction time it seemed that those differences would be accentuated by being observed with sensory attention. It is conceivable that purely "motor" attention, assuming such to be possible, might tend to obliterate the effect of such sensory differences as we used. The instructions were typewritten and were handed to the subjects before every set of reactions until they were thoroughly understood. These instructions for the "A" series were as follows: (1) "While waiting for the 'buzzer' to sound reflect on the fact that if you watch attentively for the disappearance of the light your finger will press the reaction key immediately upon its disappearance, no attention or effort being directed to the fingers. (2) As soon as the 'buzzer' sounds place fingers on key (if they are not already there) and immediately withdraw your attention from them; attending strictly to your task of noticing the instant of the disappearance of the light. (3) After the reaction has occurred, relax. No attention need be paid to the light until the 'buzzer' sounds again.

"After you become used to the experiment you will find that practically no attention need to be paid to the fingers at any time; they will automatically find their place when the 'buzzer' sounds and will react at the proper time.

"The points which it is important to remember at all times are:

"A. That your determination to react immediately on perceiving the disappearance of the light must be made once and for all before beginning the series. If it is necessary to re-inforce this determination do so in the interval between the reaction and the next warning, as you are instructed in (1). *Do not think of the hand, or of the reaction while watching for the disappearance of the light.*

"B. After the warning watch attentively for the disappearance of the light. Try to see it at the very instant in which it occurs.

"The warning will come about two seconds before the stimulus, but not exactly two seconds before. The interval may vary slightly.

"After each series inform the operator concerning your feelings during the process of reacting, and *especially be sure to mention any unusual occurrence or experiences of any kind.*

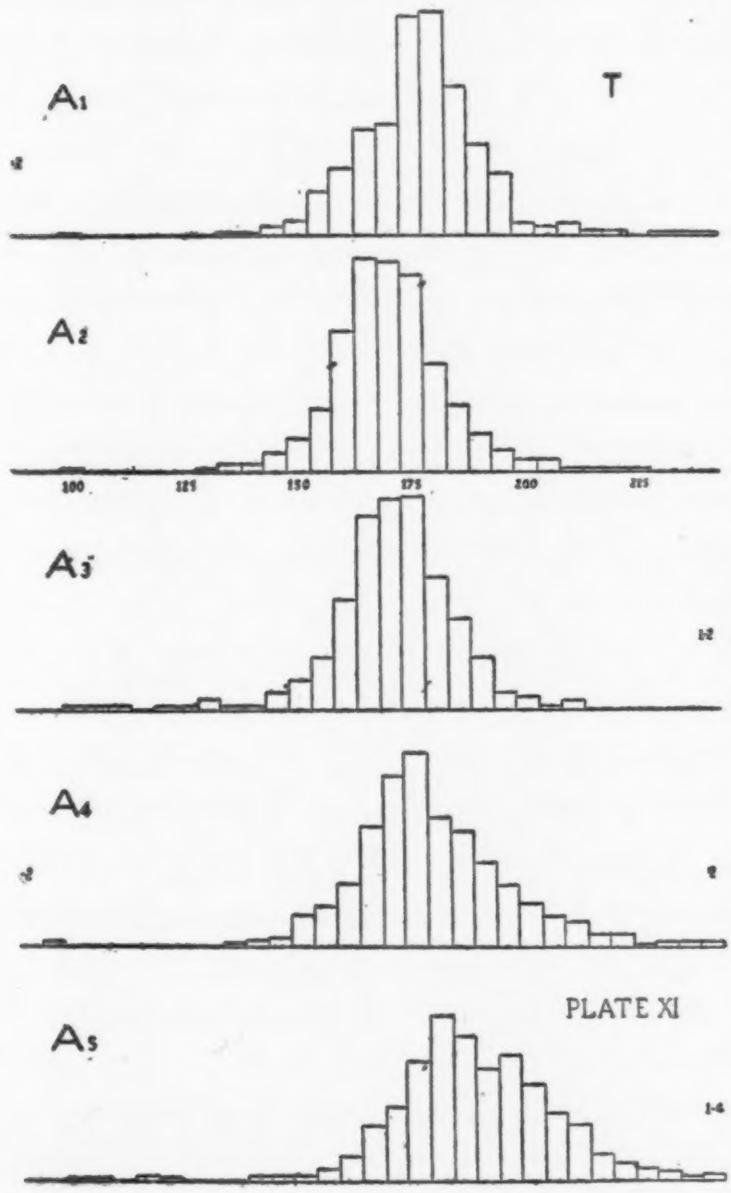
"Substitute 'appearance' for 'disappearance' when reacting to series B."

Very careful inquiries were made of the subjects from day to day to ascertain how fully the instructions were followed. As a matter of fact the instruction sheet proved entirely intelligible and its directions were fulfilled in every case almost to the letter.

As regards the cutting out of records of reactions which seemed to be unsatisfactory three simple rules were followed. The reactions which were excluded were: (1) Those which seemed to the *subject* to be abnormal, whether lengthened by inattention or outside disturbance, or anticipated. The information that they were abnormal was conveyed to the experimenter by means of the switch in the subject's room which was included in the circuit of the warning signal, and which switch operated the sounding hammer in the recording room. (2) Those which seemed to the *subject* to be abnormal *after an inquiry from the experimenter,* mediated by means of the buzzer, as to whether that particular reaction was correct or not. (3) Those which were over 300σ in length, or shorter than 60σ. These last were very few, and, as will be seen by reference to the graphs were unimportant..

T. is an undergraduate of the Johns Hopkins University in the freshman year. He reacted in full to all of the stimuli. He began reacting with A1 and proceeded in order to A5, then from B1 to B5. The averages of his reactions with their mean variations are given in Table XIII and the curves plotted from these averages in Plates XI and XII. In the table each of the figures is the average of fifty reactions and the mean variation is the average of the variations of the individual reactions from the average of the 500 reactions to that stimulus. In the reactions to the A series a phenomenon appears which is met with several times throughout the experiment. The reactions to the medium durations A2 (150σ) and A3 (66σ) are shorter than the reactions to

any other of the five durations. A1 (1^{sec}) and A4 (31σ) are very little longer, while that to A5 (10σ) is much longer than any of the others. In the opinion of the writer a difference of six or eight sigma has practically no significance in measuring reaction times. It can be seen by reference to the table that



there are three averages in the A1 series, namely 186, 185 and 190 which have a good deal to do with bringing the total average to six sigma greater than the averages of A2. In the case of A4 two or three high averages, especially one of 201, augment the total averages considerably. It is not a distortion of the truth to say that the reactions to the four longer occlusions are practically of the same length. This cannot be said of the reactions to

A5. Here there seems to be a real increase of reaction time. This stimulus was very short, 10σ, and was seen as just a flick of shadow passing across the illuminated face of the disc. T. reported on one occasion that A5 was harder to react to than any of the others of the A series, and later said that he thought that the reactions to A5, "may be slower than reactions to longer stimuli because it seems to take time to be sure whether one has seen the light go out or not". This at once suggests that there may be some intensity difference between A5 and the others of the A series. It is not impossible that there may be such difference, although none of the subjects reported it specifically. It is more probable that some matter of eye movement or eye strain comes in here; that the very short occlusion held the eyes irresistibly for a space of time during which no reaction movement could be made. This matter of eye movement and also of eye strain was observed to be an increasingly powerful factor as the duration of stimulus decreased, but was very much more noticeable in the case of A5.

Reference to the graphs shows very even distribution for all but A5. Here there is a small secondary crest.

The averages for the B series, in which the light appeared show that B1 (1 sec.) gives the longest reaction time. B2 (144σ), B3 (64σ) and B4 (25σ) give almost exactly the same time. B5 (12σ) is the shortest of all by a good deal. This was probably the hardest of all the ten stimuli to react to. This fact undoubtedly acted in this case to increase the attention of this particular subject.

T. reported that taken as a whole, the B series was easier to react to than the A series. And B2 was the easiest of all. The graphs of the B series and particularly of B2 are less evenly distributed than those of A. This indicates that the attention unconsciously relaxed in reacting to the easier stimuli, causing a greater number of lengthened reactions. But when B5 was reached it is probable that its unexpected difficulty brought about an increase of attention and a resulting lower reaction time and more even distribution.

S. is an undergraduate of the Johns Hopkins University. He

completed the entire program, going, as did T., from A1 to A5 and from B1 to B5. The averages of his reactions as recorded in Table XIV show a very high degree of regularity. His reactions are uniformly slow. His best reactions was to A5 (10σ). The reaction times to stimuli A1, A2, A3, and A4 are practically of the same length. That to A5 is about five *sigma* shorter. In the reactions to the B series that to B1 is the longest, that to B4 the shortest, and those to B2, B3 and B5 within three sigma of each other. There is not ten sigma difference between any two. When it is remembered that very slight difference of general health or of fatigue on the part of the subject, or difference of temperature in the reacting room may change the reaction time of a subject more than ten sigma, these results may be considered as alike. Furthermore, the smallness of these differences constitute a significant commentary on the absolute necessity of having a large number of reactions before any tabulation of them can mean anything at all. By choosing averages from any single day's work on the different stimuli almost any kind of result imaginable can be obtained. Generalizations founded on reactions which have not been spread over a considerable period of time may be entirely misleading.

The graphs drawn from these averages are shown in Plates XIII and XIV. The distribution is not even, but is no more uneven in any one case than another.

TABLE XIII.

Subject T. 5000 Reactions

	A1 (1 sec.)	A2 (150σ)	A3 (66σ)	A4 (31σ)	A5 (10σ)
	171	179	170	169	199
	177	170	169	175	193
	174	181	170	167	191
	186	173	174	189	185
	185	171	172	179	199
	171	177	175	189	196
	175	175	171	177	181
	178	167	178	181	189
	178	164	171	188	189
	190	169	172	201	177
Average	178.5	172.6	172.2	181.5	189.9
M. V.	7.54	13.85	12.69	21.27	14.02

	B1 (1 sec.)	B2 (144σ)	B3 (64σ)	B4 (25σ)	B5 (12σ)
	178	183	170	176	151
	166	177	172	173	150
	168	189	172	168	158
	183	173	181	167	155
	181	165	150	169	154
	165	164	170	180	157
	176	164	169	153	150
	184	159	164	159	144
	168	170	172	170	146
	197	174	171	163	145
Average	176.6	171.8	169.1	167.8	151.0
M. V.	17.64	14.52	14.16	14.76	17.99

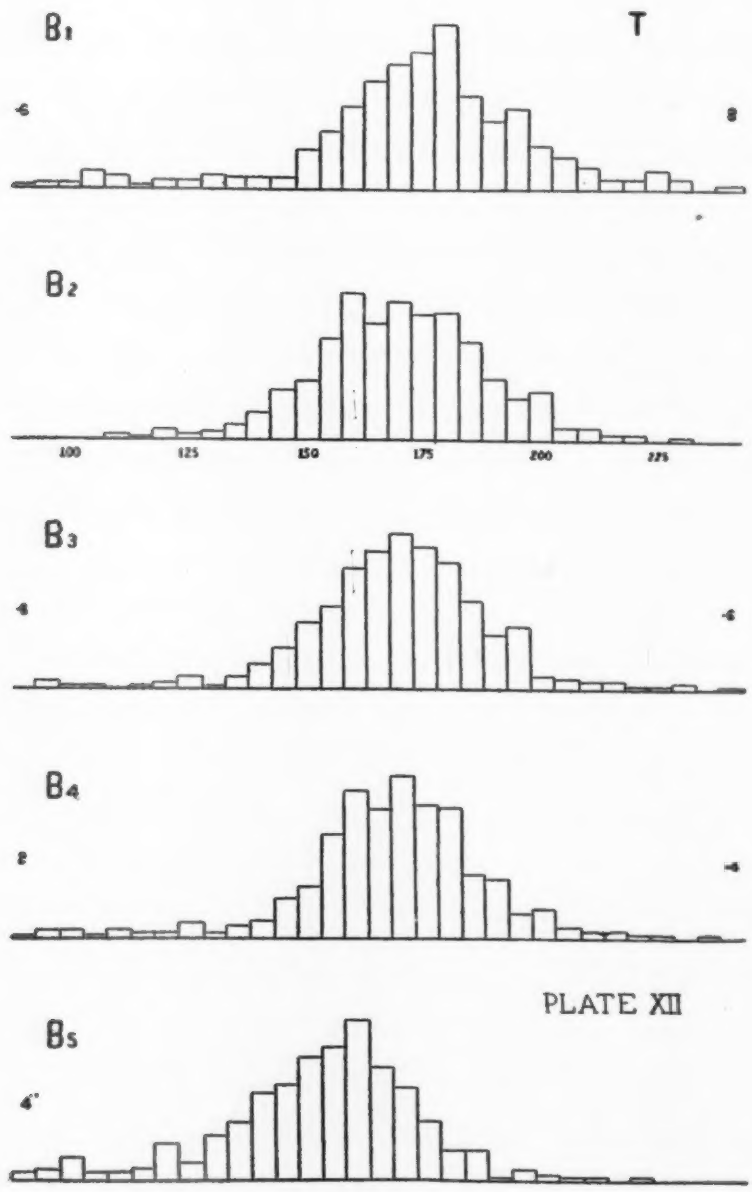


PLATE XII

TABLE XIV

Subject S. 5000 Reactions

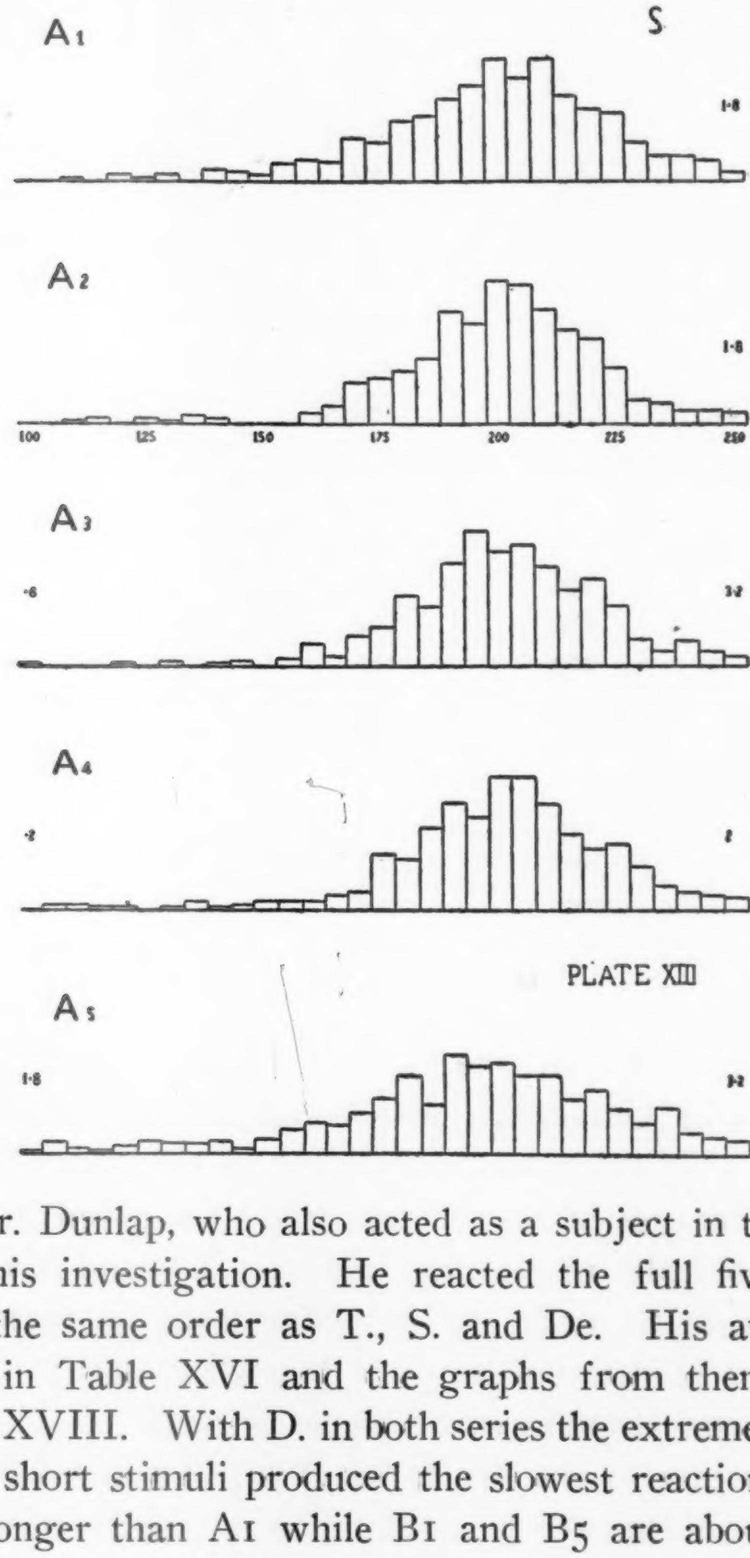
	A1 (1 sec.)	A2 (150 σ)	A3 (66σ)	A4 (31 σ)	A5 (10 σ)
	184	192	192	205	198
	178	204	197	195	192
	207	210	194	205	209
	202	200	219	199	195
	219	203	217	199	206
	205	199	212	211	216
	196	205	209	206	183
	204	199	211	206	194
	208	201	204	199	188
	212	206	200	208	188
Average	201.5	201.9	205.5	203.3	196.9
M. V.	17.53	15.83	23.63	17.87	25.52

	B1 (1 sec.)	B2 (144 σ)	B3 (64 σ)	B4 (25 σ)	B5 (12 σ)
	206	182	199	184	180
	198	202	181	188	192
	188	196	167	196	192
	199	192	184	168	183
	198	204	185	170	188
	201	193	184	181	200
	191	189	188	190	195
	199	191	203	182	206
	201	189	202	174	195
	199	201	211	180	198
Average	198.0	193.9	190.4	181.3	192.9
M. V.	22.75	18.96	22.22	19.99	18.65

De., a freshman of the undergraduate department of the Johns Hopkins University, also completed the entire program of five thousand reactions, responding in the order from A1 to B5. The averages of his reaction times are given in Table XV and are graphically represented in Plates XV and XVI.

It is difficult to make any generalizations on these averages. De. reported at the conclusion of the whole series that in general the shorter stimuli seemed easier to react to. The shortest average reaction of the two series is to A4 and B4 comes next. But note the difference in distribution of the reactions to these stimuli. The longest average is to A1 and the next longest to B2. De. said that in the cases of the longer stimuli there was a

"kind of feeling that he had to wait". There is a difference of nearly twenty sigma between A1 and A4, and of fourteen sigma between B2 and B4. Many of the graphs are somewhat irregular.



D. is Dr. Dunlap, who also acted as a subject in the auditory part of this investigation. He reacted the full five thousand times, in the same order as T., S. and De. His averages are contained in Table XVI and the graphs from them in Plates XVII and XVIII. With D. in both series the extremely long and extremely short stimuli produced the slowest reactions.

A5 is longer than A1 while B1 and B5 are about the same length. D. reported after reacting to A5 that the "reactions feel not at all different from the others. All these reactions seem

about the same. The first few after changing duration are discouraging. No change of intensity is felt. There is a perfectly perceptible feeling of dislike to the last two durations." (A4 and A5) But the time of reaction to A4 is really longer than to

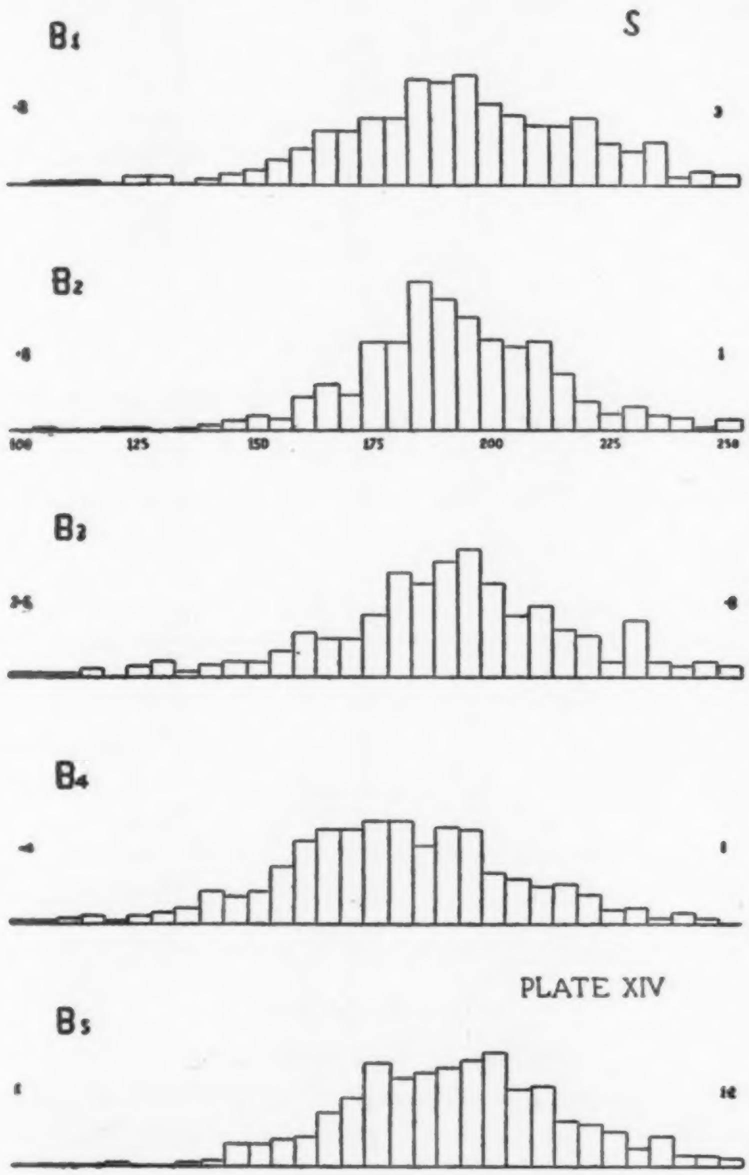


PLATE XIV

A2 and A3. B2, B3, B4 and B5 show a continued lengthening of the reaction time as the duration of the stimulus decreases. The subject reported, however that while there was some difference in intensity between B4 and B5 none was noticeable between the other Bs. The graphs show this progressive shortening plainly. They are quite irregular.

TABLE XV

Subject De. 5000 Reactions

	A1 (1 sec.)	A2 (150 σ)	A3 (66 σ)	A4 (31 σ)	A5 (10 σ)
	186	172	160	159	175
	186	178	162	173	178
	184	168	167	164	164
	183	166	179	161	164
	197	182	180	164	174
	184	169	168	155	169
	180	162	172	169	178
	185	167	170	164	198
	178	163	169	173	175
	169	171	173	164	178
Average	183.2	169.8	170.0	164.6	175.3
M. V.	10.46	18.35	11.12	8.46	14.51

	B1 (1 sec.)	B2 (144 σ)	B3 (64 σ)	B4 (25 σ)	B5 (12 σ)
	141	192	188	159	180
	170	183	185	163	174
	183	188	184	180	164
	185	187	178	167	163
	185	161	176	150	166
	170	178	159	161	159
	174	182	174	160	167
	166	170	172	176	176
	180	183	178	167	175
	179	177	179	180	183
Average	173.3	180.1	177.3	166.3	170.7
M. V.	13.01	17.25	14.16	21.28	14.45

TABLE XVI

Subject D. 5000 Reactions

	A1 (1 sec.)	A2 (150 σ)	A3 (66 σ)	A4 (31 σ)	A5 (10 σ)
	174	159	153	174	199
	174	160	164	163	176
	175	169	157	163	174
	171	175	165	167	182
	178	153	170	167	186
	173	162	162	169	171
	169	154	174	172	182
	173	180	166	165	181
	171	170	158	171	184
	170	159	178	167	181
Average	172.8	164.1	164.7	167.8	181.6
M. V.	16.44	19.86	14.35	14.0	16.02

	B1 (1 sec.)	B2 (144 σ)	B3 (64 σ)	B4 (25 σ)	B5 (12 σ)
	186	168	165	186	186
	189	168	177	180	188
	189	170	186	188	186
	193	176	183	180	180
	210	172	187	183	186
	198	170	186	180	196
	201	171	179	179	188
	169	174	178	191	196
	175	172	178	190	188
	183	166	176	182	183
Average	189.3	170.7	179.5	183.9	187.7
M. V.	20.66	14.19	14.13	13.29	13.96

Wh. is the same subject who reacted to the auditory stimuli. At the time of the visual work he was a member of the sophomore class of the Johns Hopkins University. His work was interrupted toward the end and he reacted 250 times to A3 and only 200 times to A4 and A5. Consequently the graphs for these series show very little elevation. See Plates XIX and XX. In Table XVII the averages to A show those to A4 to be the shortest. The reactions to A2, A3 and A5 are about the same length. Those to A1 are much the longest. A very similar result is seen in the B series. Here B3 has the shortest averages, B4 somewhat longer, B2 and B5 the same length and longer than B4 and B1 longer than any.

The graphs are irregular and are very much spread out.

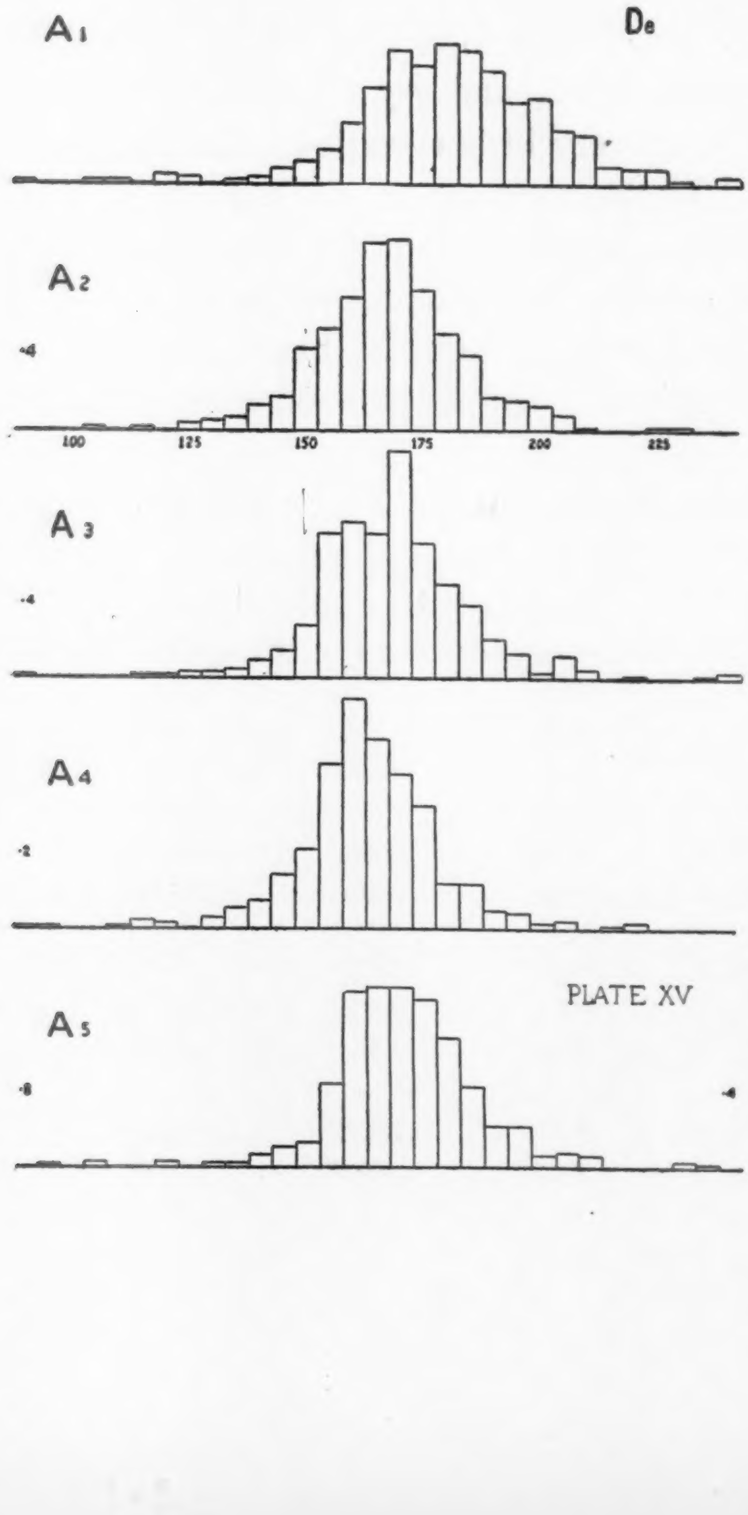
TABLE XVII

Subject Wh. 4150 Reactions

	B1 (1 sec.)	B2 (144 σ)	B3 (64 σ)	B4 (25 σ)	B5 (12 σ)
	176	200	182	184	198
	209	193	185	182	206
	206	198	176	199	209
	219	201	181	200	193
	217	199	196	211	190
	218	216	174	189	190
	214	212	194	190	207
	215	193	183	196	222
	216	196	175	193	211
	205	203	183	187	203
Average	209.5	201.1	182.9	193.1	202.9
M. V.	16.7	14.21	20.06	21.69	19.91

	A1 (1 sec.)	A2 (150σ)	A3 (66σ)	A4 (31σ)	A5 (10σ)
	199	199	202	186	190
	217	203	203	179	197
	221	195	198.	190	207
	213	196	196	191	199
	211	202	205		
	209	199			
	205	209			
	218	207			
	197	179			
	205	196			
Average	209.5	198.5	200.8	186.5	198.25
M. V.	15.43	20.03	21.23	26.31	26.25

Wi., a member of the sophomore class of the undergraduate class of the Johns Hopkins University reacted the full five thou-



sand times, according to the program. He reacted first to B; then through the series to B5, to A1, to A5. The reactions are averaged in Table XVIII and graphed in Plates XXI and XXII. His longest average is found in the reactions to A2 and A5. All the reactions to the members of the A series are nearly of the

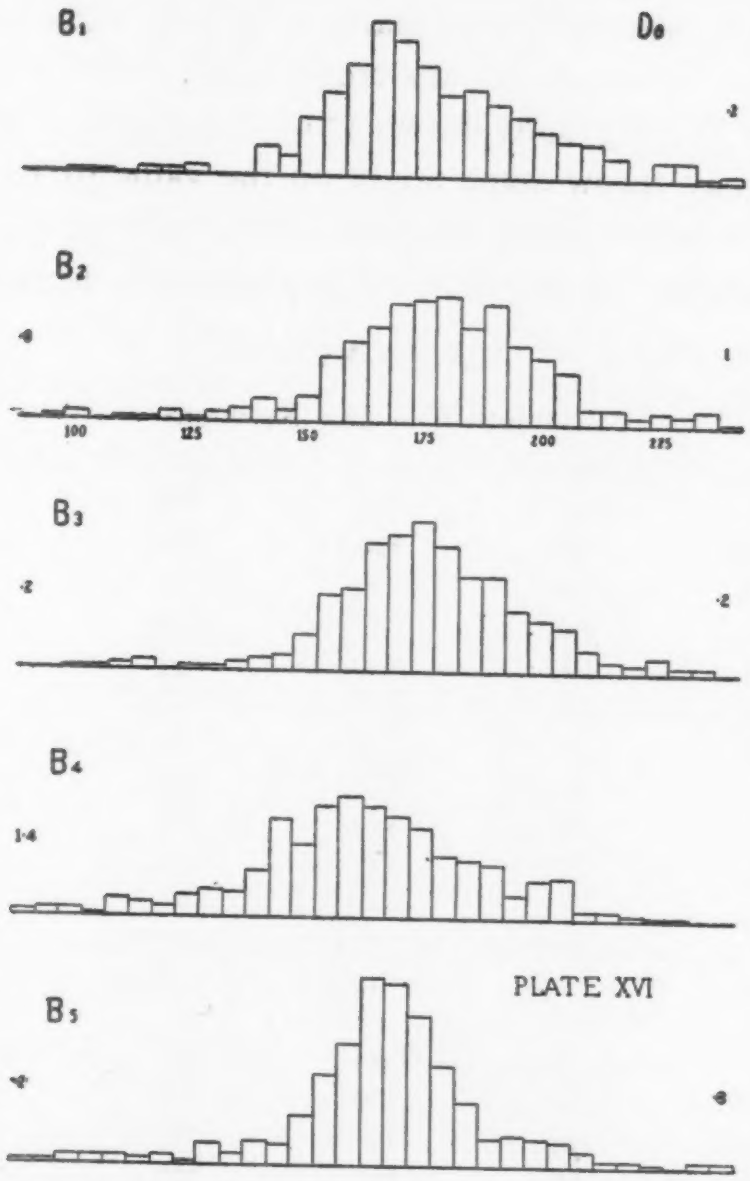


PLATE XVI

same length, that to A4 being the shortest. There is less than ten sigma difference between the most widely separated of the averages. A3 and A4, the stimuli of medium durations, are a little shorter than the others. In Wi.'s reactions to the B series we find the reactions to the extremely long B, and the extremely short B5 stimuli to be the slowest. The averages of the three medium intensities differ by less than nine sigma.

The graphs are somewhat spread out and in no case is there a secondary crest of any importance.

B. is a freshman in the Johns Hopkins University. He reacted to all the stimuli in the same order as did Wi. Here we see the reactions to the longest and the shortest of the A stimuli to be slower than the reactions to the medium durations. The three medium intensities are separated by only eight sigma. For the first time we see secondary crests equal in height to the primary crests in the graphs drawn from the reactions of B. This fact alone may throw some doubt on the value of his reactions. In the B series we find a progressive decrease in the length of reaction time as the duration of the stimulus decreases. This

TABLE XVIII

Subject Wi. 5000 Reactions

	B1 (1 sec.)	B2 (144σ)	B3 (64σ)	B4 (25σ)	B5 (12σ)
	185	191	174	168	187
	187	189	170	156	182
	186	185	174	167	183
	203	174	178	176	195
	197	183	180	175	185
	193	184	178	180	186
	194	180	173	164	197
	178	180	178	183	199
	176	182	179	181	181
	175	173	179	182	186
Average	187.4	182.1	176.3	173.2	188.1
M. V.	16.42	12.01	14.29	16.33	16.51

	A1 (1 sec.)	A2 (150σ)	A3 (66σ)	A4 (31σ)	A5 (10σ)
	188	194	199	191	189
	189	194	196	187	184
	197	195	192	190	187
	203	200	192	201	203
	200	199	190	185	195
	196	214	184	189	195
	201	189	184	189	207
	201	205	188	187	202
	186	211	199	192	216
	194	202	199	193	220
Average	195.5	200.3	192.3	190.4	199.8
M. V.	29.26	15.28	17.62	16.75	22.31

would look at first glance like a practice effect. But the subject had a long training series in reacting before any of the recorded reactions were made. And, furthermore, there is no evidence of any practice effect after B5. As soon as the subject had finished reacting to B5 he immediately began reacting to A1. See Table XIX and Plates XXIII and XXIV.

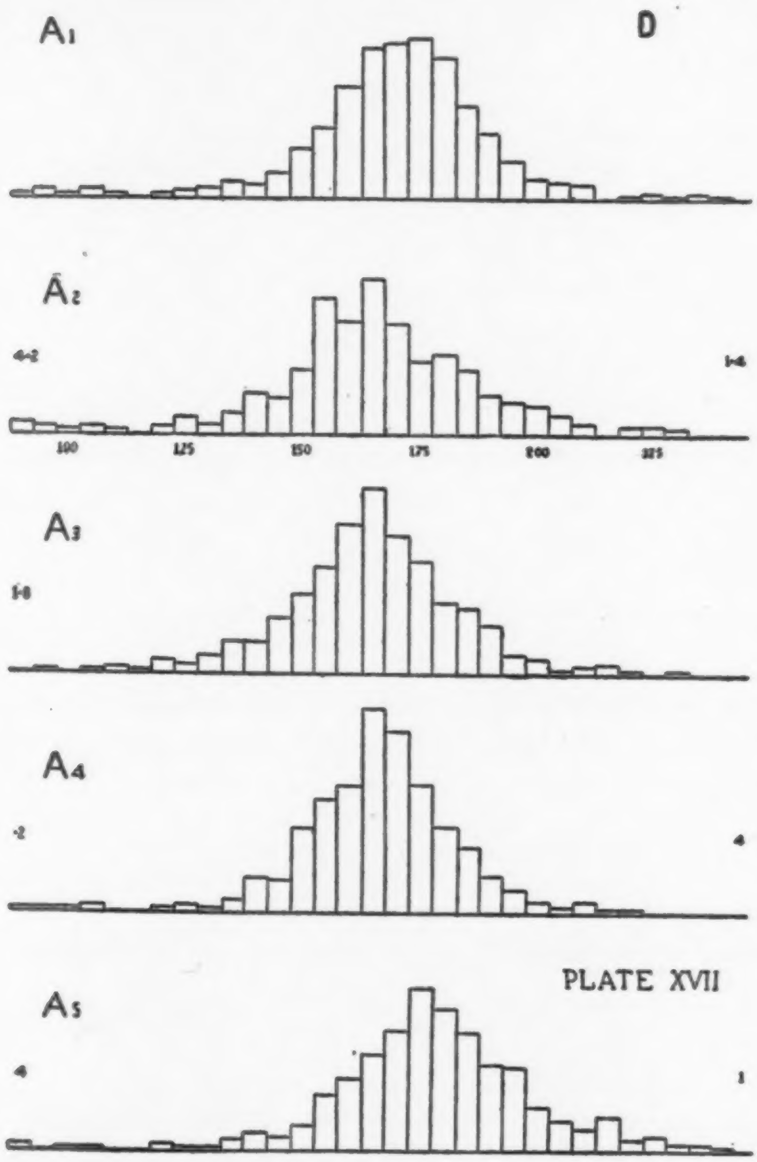


PLATE XVII

L. is a member of the sophomore class of the Johns Hopkins University. His work was interrupted by sickness before he had half finished. He reacted 500 times to stimuli B1, B2 and B3, 400 times to B4, and 200 times to B5, and all the A series. The averages of his reactions are given in Table XX and the graphs in Plates XXV and XXVI. The difference between the longest and the shortest average in the A series is 17.55σ. The

longest averages is to A2. There is one very long daily average included in this total. The graph of A2 is seen to be very much spread out, more so than any of the others, although all the graphs of this subject's reactions are elongated. A1, A3, A4 and A5 are practically of the same length. In the B series B1 and B4 are the longest, B2, B3, and B5 about the same.

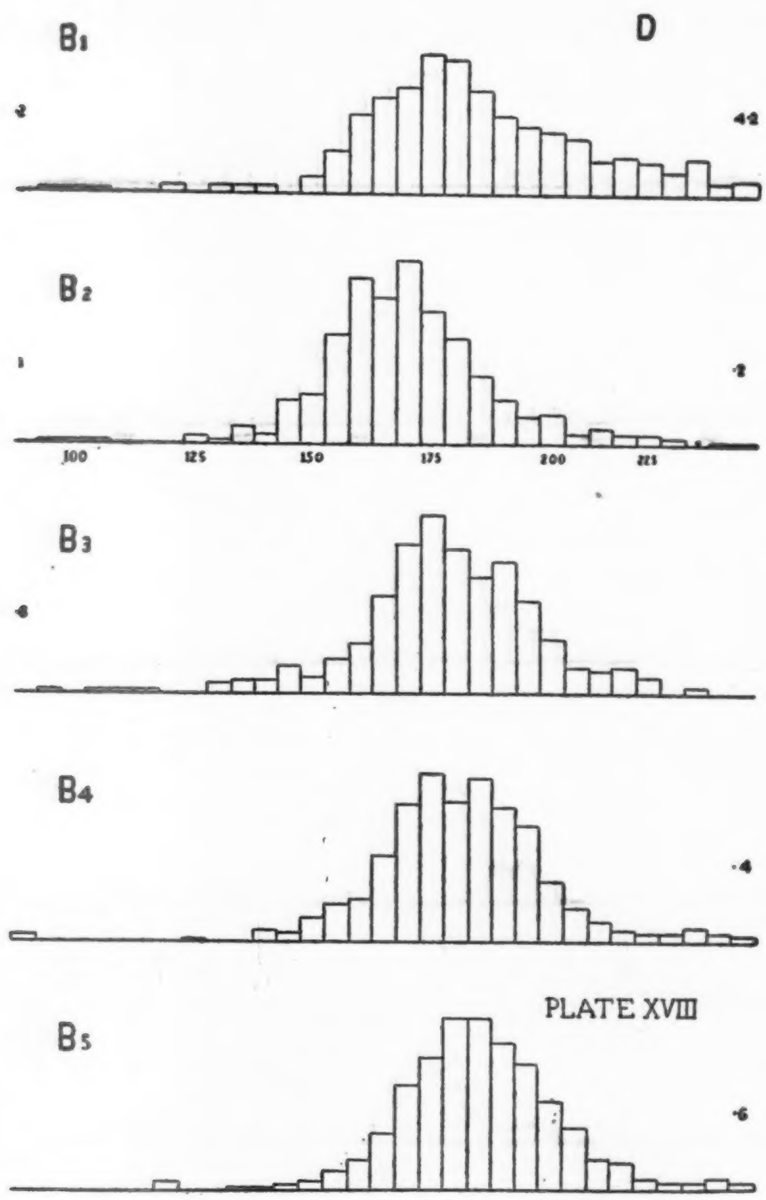


PLATE XVIII

TABLE XIX

Subject B. 5000 Reactions

	B1(1 sec.)	B2(144σ)	B3(64σ)	B4(25σ)	B5(12σ)
	195	180	162	171	161
	193	179	162	164	163
	172	165	165	164	158
	200	165	161	161	158
	201	176	157	153	154
	201	186	170	157	158
	191	178	169	157	153
	185	176	169	157	150
	194	163	169	163	146
	177	168	192	156	151
Average	190.9	173.6	167.0	160.3	155.2
M. V.	19.47	16.80	19.11	33.57	19.58

	A1(1 sec.)	A2(150σ)	A3(66σ)	A4(31σ)	A5(10σ)
	185	139	155	147	169
	182	154	154	152	165
	175	126	155	160	179
	182	174	151	158	176
	180	154	170	160	171
	178	156	166	166	185
	179	155	163	153	183
	150	151	152	163	175
	132	150	163	154	177
	152	149	159	152	175
Average	169.5	150.8	158.8	156.5	175.5
M. V.	21.49	26.07	23.15	14.38	18.96

TABLE XX.

Subject L. 3100 Reactions

	B1(1 sec.)	B2(144σ)	B3(64σ)	B4(25σ)	B5(12σ)
	205	190	185	214	208
	217	199	184	200	205
	205	188	190	208	196
	216	204	194	203	192
	216	201	196	209	
	206	196	204	206	
	201	199	193	213	
	213	200	219	207	
	219	204	225		
	202	204	205		
Average	210.0	198.5	199.5	207.5	200.25
M. V.	17.05	12.82	21.39	14.87	15.79

	A1 (1 sec.)	A2 (150σ)	A3 (66σ)	A4 (31σ)	A5 (10σ)
	186	195	204	184	198
	192	215	194	193	193
	192	209	192	198	190
	190	211	186	187	200
Average	190	207.5	194	190.5	195.25
M. V.	17.98	18.55	15.54	16.11	24.

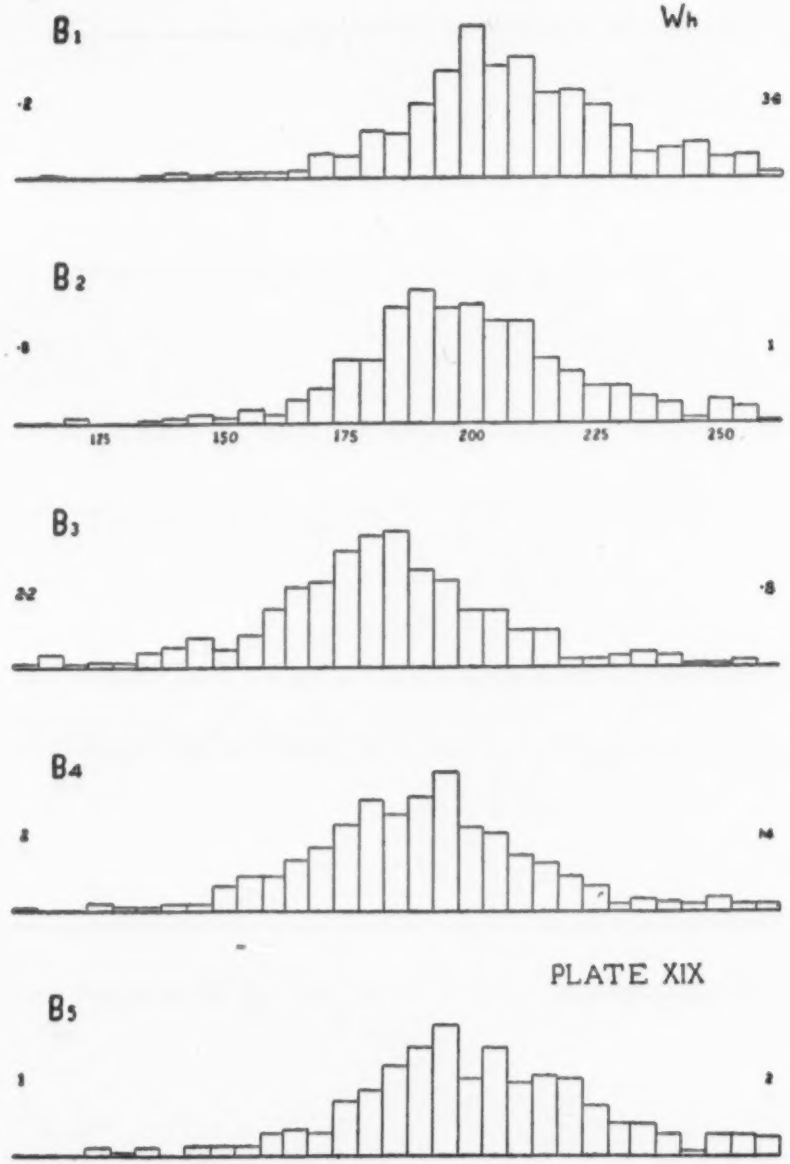


PLATE XIX

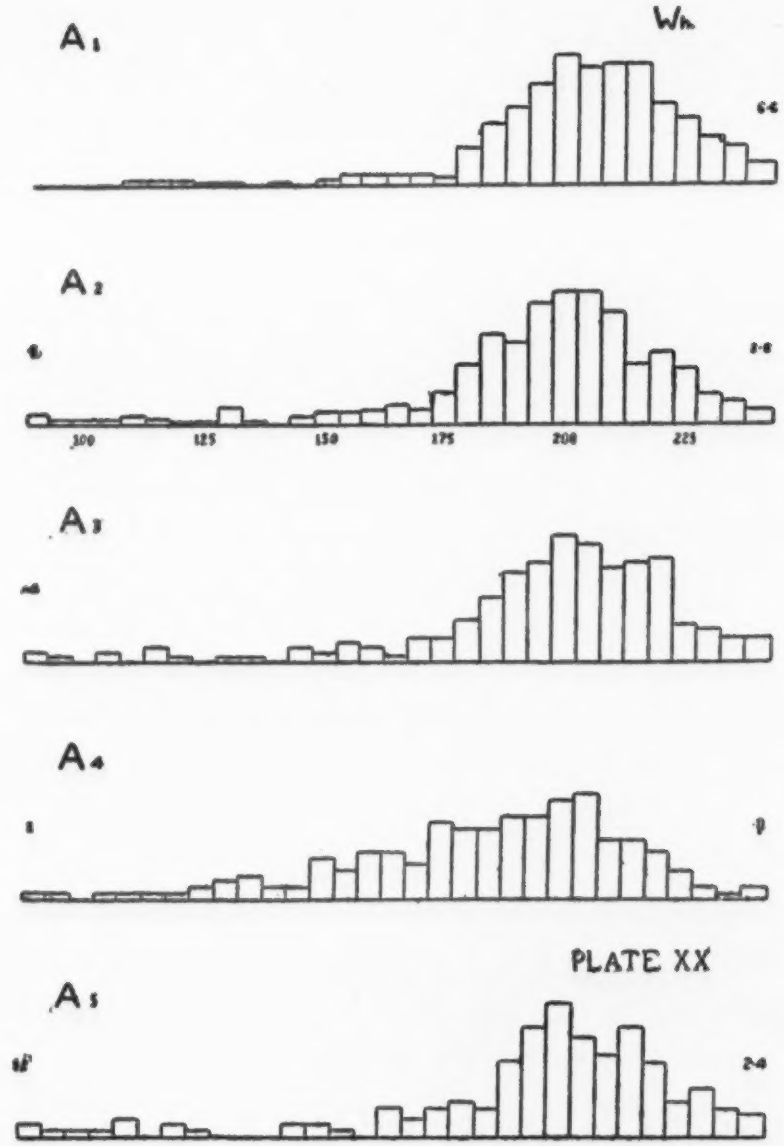


PLATE XX

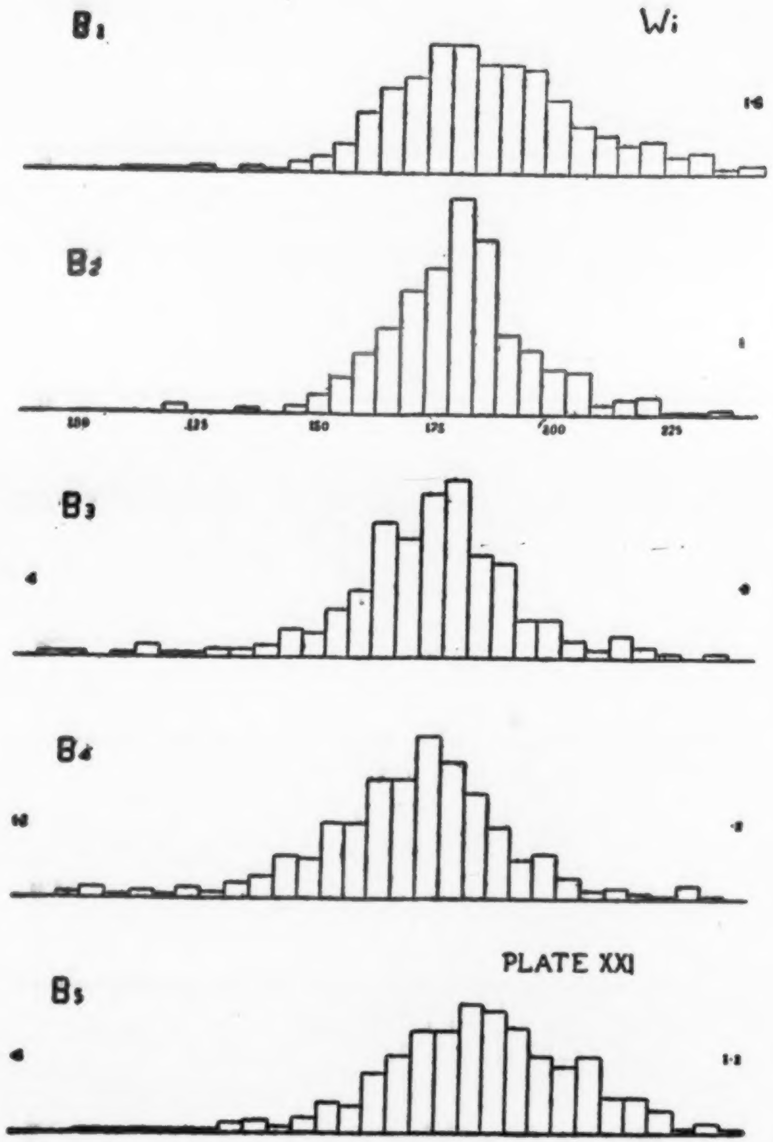


PLATE XXI

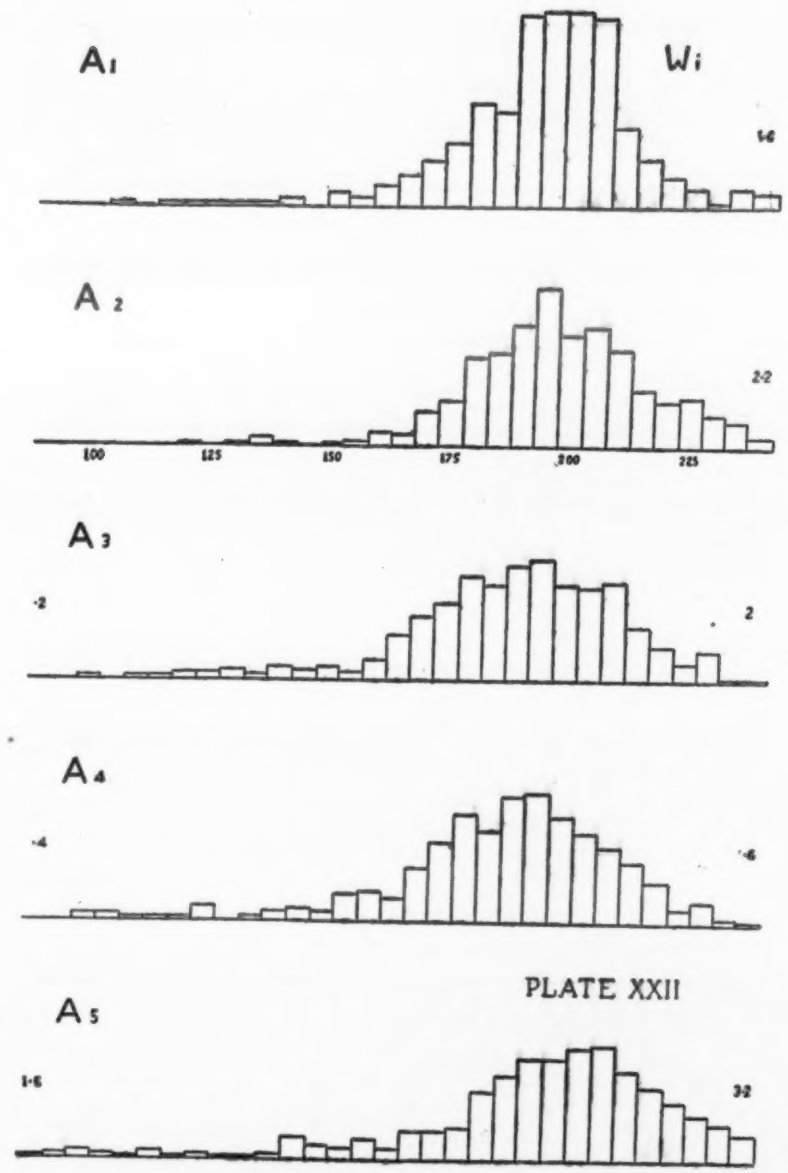


PLATE XXII

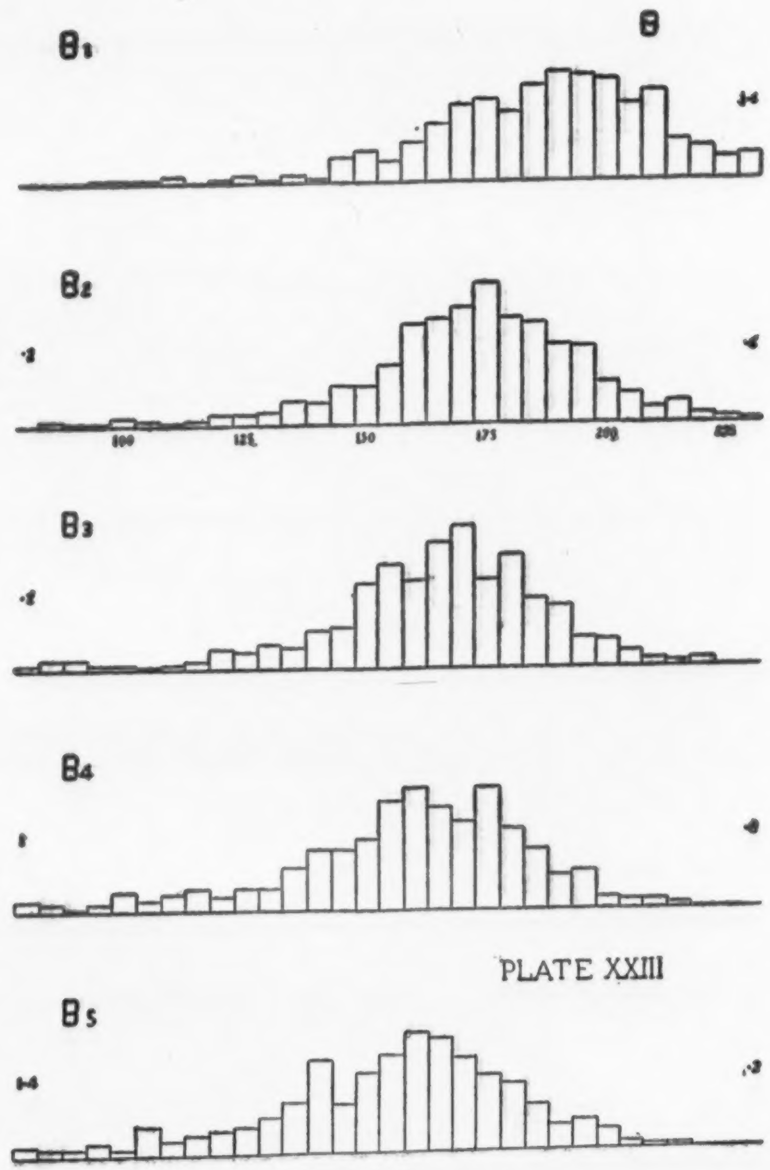


PLATE XXIII

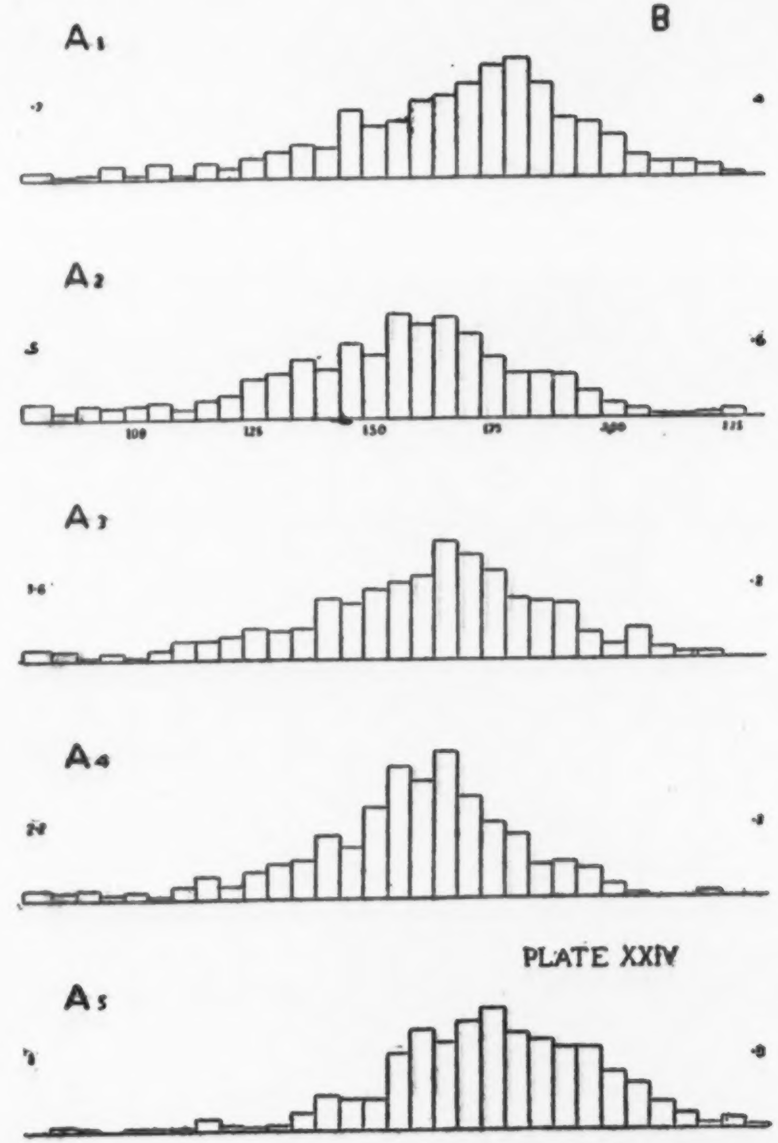


PLATE XXIV

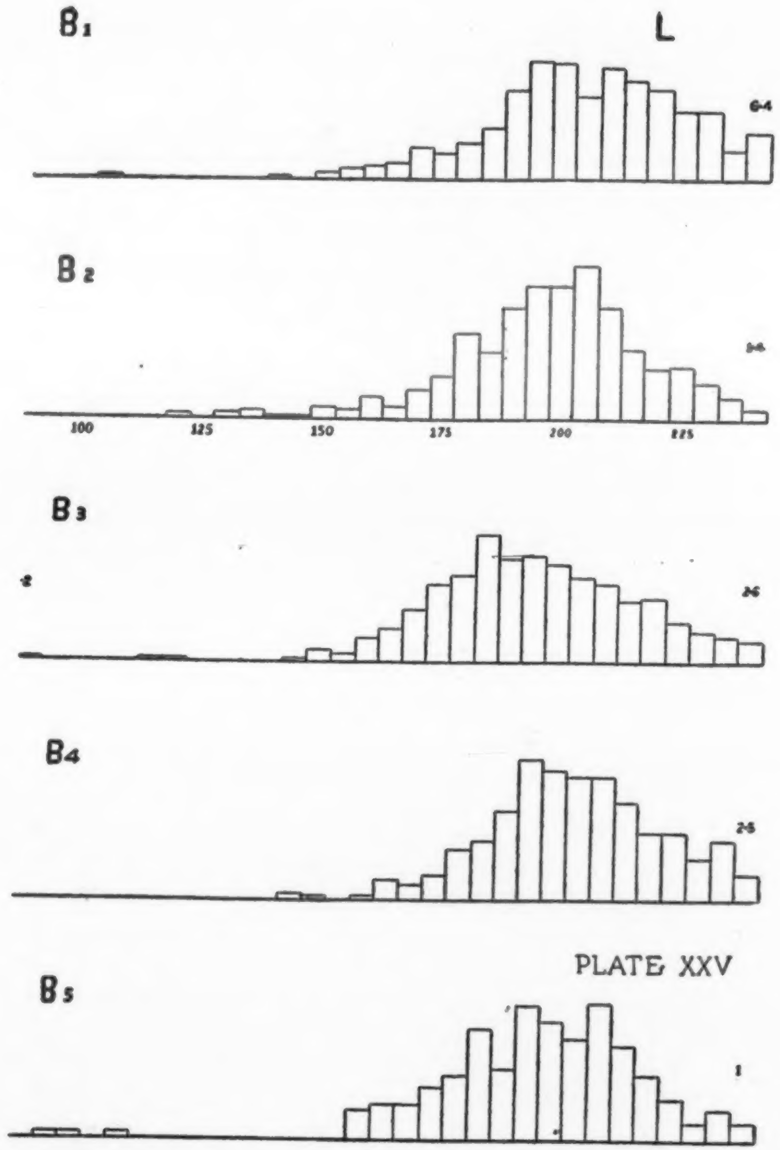


PLATE XXV

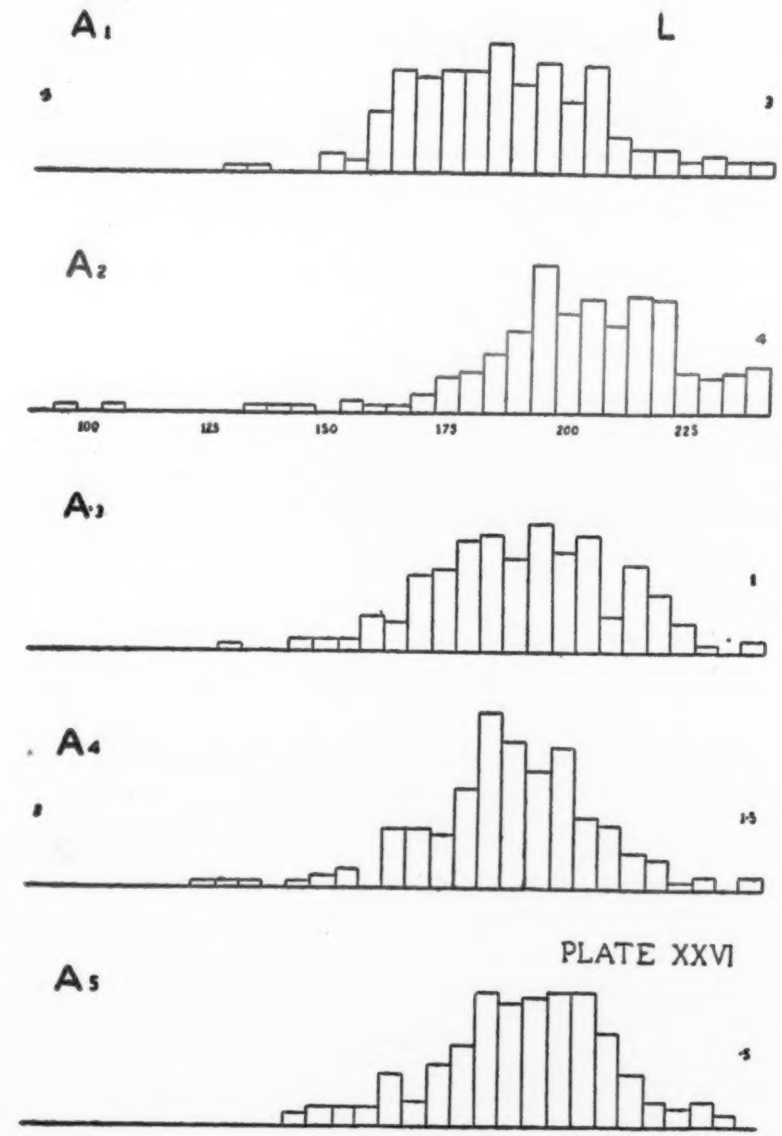


PLATE XXVI

IV. CONCLUSION

The results of the foregoing experiments are not easily arranged to establish any definite rule. But they certainly do not support any hitherto promulgated principle of the relation of stimulus to reaction time. They do not follow a rule analogous to Weber's law, as the results which Froeberg obtained apparently did. Nor is there any evidence of increase of reaction time with decrease of stimulus duration. In fact the results, in so far as they are positive, point in an opposite direction. The longer the duration of stimulus the longer does the reaction time tend to be.

The results on the relation of the duration of auditory stimulus to reaction time are, I think, unequivocal. Duration of auditory stimulus of the lengths used does not materially affect reaction time. If an auditory stimulus be sufficiently long to enter consciousness, any prolongation of that stimulus up to the greatest duration we used will not affect the reaction time, provided the intensity be kept constant.

The results of the reactions to visual stimuli are not so clearly uniform. A very small number of *sigma* separates the longest from the shortest average in the results of most of the subjects. This is noteworthy. If the reaction averages of all subjects to each stimulus be themselves averaged the smallness of the differences is more than ever noticeable. Such an averaging is not defensible on methodological grounds, and no deduction can be drawn from it alone, but it furnishes a convenient birdseye view. The results are so averaged in the following table:

TABLE XXI.

	A1	A2	A3	A4	A5	B1	B2	B3	B4	B5
T........	178.5	172.6	172.2	181.5	189.9	176.6	171.8	169.1	167.8	151.0
S.........	201.5	201.9	205.5	203.3	196.9	198.0	193.9	190.4	181.3	192.9
De.......	183.2	169.6	170.0	164.6	175.3	173.3	180.1	177.3	166.3	170.7
D........	172.8	164.1	164.7	167.8	181.6	189.3	170.7	179.5	183.9	187.7
Wh.......	209.5	198.5	200.8	186.5	198.2	209.5	201.1	182.9	193.1	202.9
Wi.......	195.5	200.3	192.3	190.4	199.8	187.4	182.1	176.3	173.2	188.1
B.........	169.5	150.8	158.8	156.5	175.5	190.9	173.6	167.0	160.3	155.2
L.........	190.0	207.5	194.0	190.5	195.2	210.0	198.5	199.5	207.5	200.2
	187.6	183.2	182.5	180.2	189.0	191.9	183.5	180.2	179.2	180.9

If in the tables the results of the B series be examined carefully it will be seen that in the case of T. there is a regular decrease in the reaction time as the stimuli become shorter. The total decrease is 25.6σ. With S. there is a regular decrease from B1 to B4, B4 being 16.7σ shorter than B1. B5 is somewhat longer than the two preceding durations. With De. there is no regular decrease, but B4 is 7σ shorter than B1. D. shows very nearly the same decrease as De. In both cases B5 is longer than B4. Wh. makes a regular decrease from B1 to B4 totalling 16.4σ. Wi. has very regular decrease from B1 to B4, totalling 14.2σ. B. has a decrease of 35.7σ from B1 to B5 and L. though he shows no regular decrease, makes the average reaction to B4 2.5σ shorter than that to B1. Thus in the B series five subjects show a regular decrease in reaction time as the duration of the stimulus decreases. The other three subjects react more quickly to B4 than they do to B1. The successive average decrements are small, but inasmuch as they are based upon a very large number of reactions, and as they are found in five subjects, and are, at least, not contradicted by the other three subjects, they cannot be without significance.

The results from the A series while they do not strongly substantiate the suggestion of the B series, certainly do not contradict it. In five cases A4 is shorter than A1. In one case, that of T., A4 is 3σ longer than A1. In the case of S. A4 is 1.8σ longer than A1 and in the case of L. A4 is $.5\sigma$ longer than A1.

It is not possible that the progressive shortening is due to the effect of practice. Each subject underwent a thorough training in reacting before any reactions were recorded. This preliminary series was kept up until the shortening effect had disappeared. And then it will be seen by reference to the tables that there is no improvement to be seen within the series of reactions to any one stimulus.

A5 and B5 do not fit into the suggested rule of progressive decrease of reaction time to decrease in length of stimuli. The reason for this probably lies in the fact that the intensity of A5 and B5 was less than the intensity of the other stimuli. That a decrease in intensity of stimulus increases the time is established.

Wundt[60] goes into the question in some detail. He says that the length of the reaction time varies in general inversely as the intensity of the stimulus. He found that the reaction time was longest in the neighborhood of the stimulus threshold. With increasing strength of visual stimulus the reaction time at first decreased very fast, but more slowly in reacting to medium intensities. There were apparently wide limits in which there was little or no change in reaction time. With auditory stimuli of different strengths the same general law was found to exist. Von Kries and Auerbach[56] obtained a wider application of the same law with the use of electrical stimuli. They found a rapid decrease of reaction time corresponding to increase of strength of weak intensities. Wundt holds that as the intensity still further increases the reaction time will begin to increase. Exner[28] found different results on this point. He believed that a very strong stimulus which caused a shock produced a great shortening of the reaction time. Von Kries and Auerbach found that discrimination time was shorter for strong stimuli than for weak. Berger[12] investigated the validity of Wundt's law. He obtained six intensities of visual stimulus by inserting grey glasses between the eye and the source of light, and two higher intensities were produced by using a condensing lens. He found a very regular decrease of reaction time as the intensity of the stimulus increased. These results were almost paralleled by reactions to electrical stimuli. Reactions to four different intensities of auditory stimuli produced by letting a ball drop from the Hipp Fallapparatus at heights of 60, 160, 300 and 500 mm. gave less regular results.

Berger concluded that reaction time varies inversely as the intensity of the stimulus, more markedly the nearer we approach to the stimulus threshold. He holds this to be true not only for sound stimuli as pointed out by Wundt and for electrical stimuli as investigated by Von Kries and Auerbach, but also for light stimuli. Berger asserts that it seems probable that Wundt's statement that reaction time increases with stimuli of very strong intensity is true, although he admits that his own investigation does not prove it.

The number of subjects used in this investigation was entirely inadequate, there being but one, J. M. Cattell, beside Berger himself.

This fact, and the fact that each of these two observers reacted only 150 times to each intensity detracts from the significance of the results of this investigation.

Cattell and Dolley[15] working on reaction time to dermal stimuli of various kinds (electrical, touch, etc.) found that "the time of reaction was shorter when the intensity was greater".

G. Martius,[42] investigated the influence of the intensity by using the tones C′ C c′ c‴ c⁗ and a noise as stimuli using two intensities of each, a strong and a weak. He comes to the conclusion that it is not strictly accurate to say that reaction time decreases with increasing intensity of impression, for practice and attention will equalize reaction times to different intensities of tones within the scale used.

Martius acted as subject in this experiment with one other subject. The experiments never numbered more than 20 for any particular stimulus and frequently were as few as 11. They are entirely too inadequate in number to justify any positive assertions based upon them.

Slattery[50] measured the time of reaction to (1) different intensities of tone, (2) tones of different pitch (3) electrical stimuli of different intensities. He sums up his results on intensity of tone by saying that reaction time does not vary with intensity of stimulus in any degree that can be detected, thereby disagreeing with Wundt and the majority of observers, but agreeing with Martius.

It should be said that the number of subjects and of actual reactions recorded by Slattery in the investigation was too small to be a sufficient basis for any generalization whatsoever, and especially so for a generalization which is somewhat revolutionary in its nature.*

* It seems to the present writer to be a waste of space to print and of time to read any article based on such a paucity of experimental material as is reported in this article and in that of Martius. Nor are these two writers alone in this fault. Far too many men have rushed into print to enunciate with all confidence conclusions based upon an utterly inadequate number of observations.

Froeberg,[32] in the article referred to above, worked with variations of the intensity and of the magnitude of stimulus as well as of duration. He worked with visual and auditory stimuli. Effects of variation of intensity on time of reaction was first investigated. This investigation was divided into two parts. In the first part the intensity and the size of the stimulus were varied and in the second the intensity and duration. The greatest intensity was the Milton-Bradley white baryta paper designated as 100. The other intensities were obtained from Hering's greys, and their relative brightness tested by the size of a white sector on a color mixer which produced exactly the same shade. Four were chosen besides that of 100, namely 56, 25, 16 and 10. Four subjects were used, each reacting 400 times to each intensity. From the results the author concludes that the time of reaction tends to increase arithmetically as the intensity of the stimulus decreases geometrically.

The effect of the variation of the size of the stimulus on the time of reaction was next investigated. Five sizes of stimulus were used.

The results of these tests show that the time of reaction increases with decreasing size of the stimulus. Over a limited range this increase is made by approximately equal arithmetical increments as the size of the stimulus decreases geometrically, but as the threshold is approached the increase becomes more rapid.

The experiments with auditory stimuli of different intensities obtained by dropping a steel ball from different elevations lead Froeberg to the conclusion that the time of reaction increases with decreasing intensity of sound. On account of the lack of a reliable measure of the physical intensity of sound no definite relation of the intensity to the reaction time can be stated, but it can be said that there is a general inverse relation.

The text-books in general take the ground that as a general rule reaction time varies inversely as the intensity of the stimulus.*

* James, "Principles of Psychology" vol. 3, p. 96; Külpe, "Outlines of Psychology" p. 407; Ladd and Woodworth, "Elements of Physiological Psychology" p. 479.

While there is some disagreement as to the exact meaning of the experiments with different intensities of stimuli (as between Külpe on one hand and Cattell and Dolley on the other as regards the effect of different intensities of electrical-cutaneous stimuli) yet the final conclusion that in the realm of moderate intensities the time of reaction varies inversely as the intensity of the stimulus, is the general conclusion of most observers

According to the foregoing investigations, which seem to have established the rule that decrease in intensity produces increase in reaction time, we may reasonably assume that the extreme shortening of stimulus-duration may, through the consequent reduction of intensity, have resulted in producing a prolonged reaction to A5 and B5.

It is very probable that reactions to visual stimuli of various durations vary, not inversely, but directly with the durations of those stimuli, but not in the same ratio. We are more accustomed to react quickly to short auditory impressions than we are to short visual impressions. Perhaps this is why the results to the auditory stimuli are negative.

Froeberg's results with visual stimuli do not agree with mine. His subjects presumably were all acquainted with the effect of intensity variations on reaction time. They may have expected the results which they finally obtained. At least this possibility is not excluded in Froeberg's paper.

The subjects of my experiment with visual stimuli were, with one exception, absolutely naïve. They knew nothing at all of the effect of intensity upon reaction time. Their reactions were not modified by pre-conceptions of any sort. Dr. Dunlap, of course, was an exception. But he was careful not to learn the result of his own reactions nor those of the other subjects until he had finished reacting.

In the auditory series, which was completed before the visual work was commenced, three subjects had some knowledge of the results of work with varying intensities of stimulus. Obviously, this did not affect their results.

The original problem which suggested the present experiment

was that of the investigation of the characteristic difference of reaction time to stimuli of the visual and auditory modes.

The explanation of this difference which is most generally adopted is that there is a certain latency in the response of the visual end organs, due to the fact that the photochemical process is quite slow. It was partly to investigate this that the series was introduced having the disappearance of a light as stimulus. The shortest disappearance or occlusion stimulus used was 10σ. In this case there was a continuous visual stimulation, suddenly and completely interrupted, and reinstated 10σ later. The interruption of the light was plainly perceivable, no subject had any difficulty whatsoever in seeing it. As the terminal lag of the visual sensory process is demonstrably longer than the initial lag, the total time of the drop in the process, when the stimulus is cut out and then readmitted 10σ later, must be less than 10σ. Probably the rise in the process commences at the point at which the stimulus is readmitted: but at any rate the process cannot continue to fall beyond that point. A distinctly noticeable change in the process occurs, therefore, within 10σ or less after the occlusion of the stimulus. The delay of the appearance of a perceptible change in visual sensation due to the lag of the sensory process cannot, therefore, in this case account for even a 10σ lengthening of the visual reaction as compared with the auditory reaction—there being presumably some lag even in the auditory process. Since, as said above, the visual process rises more quickly than it falls, and since, moreover, the reactions to the occlusion of light differ little from the reactions to the appearance of light, we must conclude that in this case also, the mere delay in the appearance of the change cannot account for the lengthening of the reaction.

Inasmuch as the energy of even a very moderate auditory stimulus is much greater than that of a strong visual stimulus the characteristic difference may be explained by this fact.

The results of the present investigation suggest another possible explanation. We are far more accustomed to react to short sharp auditory stimuli than to equally short visual stimuli. Practically all visual stimuli exert a more prolonged effect upon the

rods and cones than an auditory stimulus does upon the organ of Corti. This investigation has made it probable that reactions are slower to visual stimuli of a somewhat prolonged nature than to shorter stimuli. It should be noted that in this investigation the subjects completed reacting to all the stimuli of a certain duration before they reacted to the stimuli of another duration. With our apparatus it is impossible to mingle the stimuli of various durations indiscriminately. Therefore, the subjects had a certain adaptation to the length of stimulus which was to be reacted to. This adaptation is what affected the length of reactions. Exactly the same kind of adaptation is present when reacting to any stimulus. If the stimulus is visual a certain length is expected. It may be that it is this fact which prolongs reactions to visual stimuli over and above reactions to auditory stimuli.

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